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INCORPORATING THE METALLURGICAL ENGINEER

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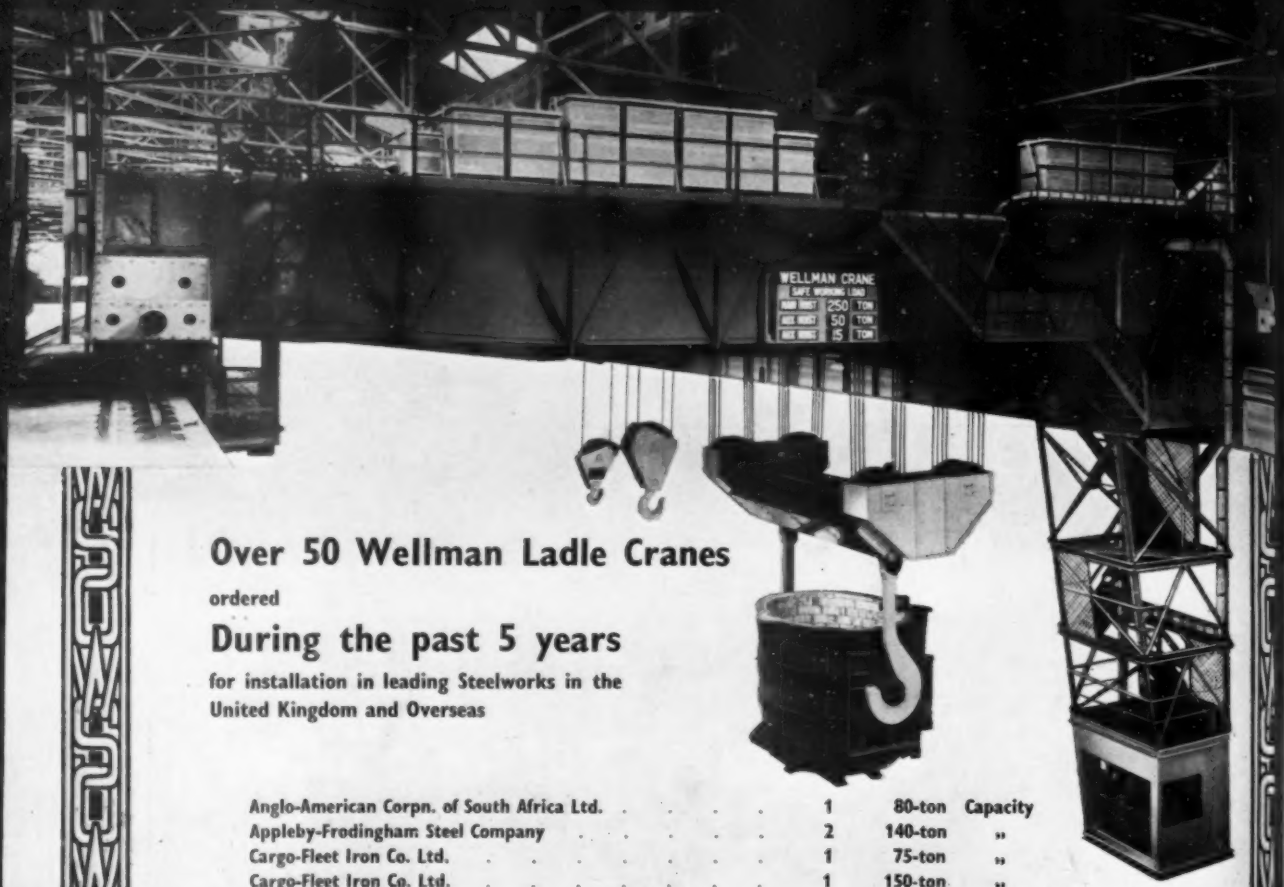

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METALLURGIA

THE BRITISH JOURNAL OF METALS

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September, 1954 Vol. L. No. 299

Co-operative Effort

THE story of the iron and steel industry has been one of ever increasing output based on the development programme drawn up in 1945. Indeed, to those not directly concerned, the successive announcements of record production figures began to get a little monotonous. Nevertheless, growth of the industry in the post-war years represents no mean achievement, accomplished as it has been in the face of considerable difficulties. In his review, in the Seventh Hatfield Memorial Lecture, of the development of the iron and steel industry in this country during the period 1929–54, Dr. T. P. Colclough, drew attention to the fact that no vital new principle for the making of iron or steel, or for the rolling and shaping of steel, has been discovered during the last quarter century. There has, however, been a much greater application of scientific knowledge to the industry.

The introduction of continuous cold rolling mills and electrolytic tinning lines has revolutionised the Welsh tinplate industry, and has resulted in the closing down of many smaller units: this is probably the most spectacular change on the fabrication side of the industry. In steelmaking, improved designs of open hearth furnace have been based on experiments with models designed to facilitate the study of gas flow through the chamber, whilst the introduction of oxygen into the steelmaking bath is now practised on a plant scale. The most significant change in blast furnace practice has been the increase in production per furnace in blast, the second most important feature being the greater use of ore preparation facilities, including bedding and sintering plants, whilst high top-pressure operation has found limited operation.

It is not possible to divide the post-war developments into purely operational or purely engineering categories, as many of them are a mixture of the two, and for them credit must go to chemists, metallurgists, engineers and operators—both individually and collectively—as well as to the managements whose foresight made the need for them apparent. The Seraphim project of the Appleby-Frodingham Branch of the United Steel Companies—which is described elsewhere in this issue—provides an excellent example of such a co-operative effort, particularly as it stemmed, not only from increased demand for pig iron, but also from the need to modify the blast-furnace operating conditions.

About 1859 it was found that there were large deposits of ironstone in the Scunthorpe district of Lincolnshire. At first, ore was transported to South Yorkshire for smelting, but new companies were formed, who brought coal to the district and smelted the ironstone near to its source. With the advent of steel, the ironmakers of Scunthorpe built melting shops for its manufacture from pig iron, and as time went on rolling mills for its fabrication were established. So it came about that what 100 years ago was a cluster of five villages, with a combined population of 1,500 people, is now a town of more than 50,000 inhabitants, mostly dependent on the iron and steel industry for a livelihood.

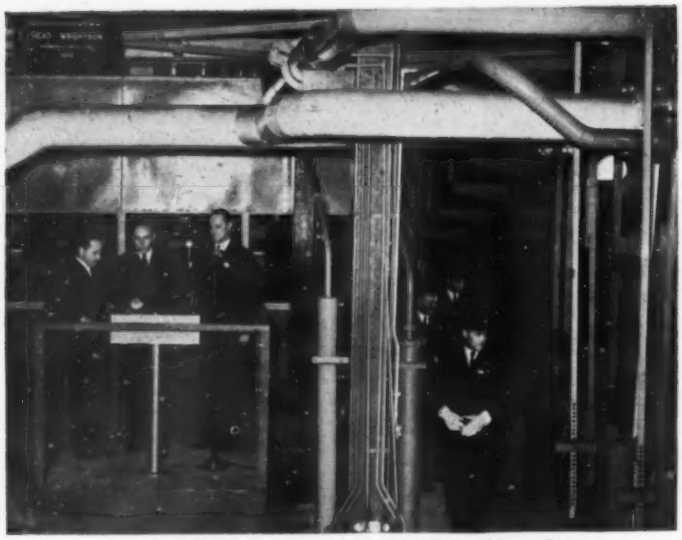
Since the beginning of the present century Scunthorpe has been prosperous because of its ability to convert the low-grade local ironstone into steel at an economic price, and during that period few can have considered the possibility that such prosperity could cease. Nevertheless, the low grade ore was gradually and almost imperceptibly deteriorating, and by 1945 the responsible heads of Appleby-Frodingham were becoming more and more apprehensive about the technical difficulties of making iron from these ores, difficulties which were still increasing.

Just before the war, an ore bedding and sintering plant had been installed to enable the deteriorating ores to be dealt with, but by 1945 there was a demand for yet easier burdens than the ore preparation plant could supply. There was urgent need for a discovery or development which would enable economic and efficient production to continue, and which would prevent what appeared to be the worst of all possibilities, the failure of the Company's iron production from home ores some time between 1955 and 1960.

The Frodingham ore contains a high percentage of lime, and it has been the practice to smelt it with siliceous Northants ore to form a self-fluxing burden, but the high metallurgical load arising from the large slag volume results in high coke consumption, and any means of improving this situation would be of considerable value. A good deal of experimental work was devoted to efforts at concentrating the ores, but whilst an oxidising roast followed by a magnetic concentration gave good results with Frodingham ore, it was found to be impossible to concentrate the Northants ore in which the iron is present as chamosite.

The advantage of big blast furnaces could only be exploited to the full, however, with better materials than had hitherto been possible. Improved coke quality was achieved as a result of several years painstaking work in the laboratory and on pilot ovens. Although ideas of concentration had had to be abandoned, it was known that sinter could be introduced into the burden with advantage. Much laboratory and plant scale work was necessary, however, before a satisfactory sinter could be produced from the low quality home ores—a very different matter from sintering rich imported ores. As the sintering process was being perfected, blast furnace trials with increasing proportions of sinter established the very real advantages of practically 100% sinter as the iron-bearing constituent of the burden.

Thus it is that the Seraphim scheme, comprising blast furnaces operating on 100% sinter, and the necessary plant for producing the sinter, is the outcome of laboratory experiments, pilot plant trials, and full-scale operating experience combining to provide the information necessary for the design and erection of the plant. Truly an example of co-operative endeavour.



Sir Archibald Forbes starts the Seraphim plant.

United Steel Companies' Iron Making Developments

"Seraphim" Plant now in Operation at Appleby-Frodingham

WHEN, on 29th July, Sir Archibald Forbes, Chairman of the Iron and Steel Board, simultaneously started up a sinter strand and lit a blast furnace half a mile away, he set the seal on a scheme of reconstruction at the Appleby-Frodingham Branch of the United Steel Companies which has involved the expenditure of more than £26 million since the end of the war.

In 1945, the various units of the steel industry had a back-log of repair and reconstruction work which had been held up by wartime conditions. In addition, there was an increased demand for steel by the consuming industries, and a scheme for the expansion of the industry as a whole was prepared. This first development plan has now been completed, and a second plan is in process of being translated into fact. Account has had to be taken of the changed operating conditions, which, owing to a diminition of the supply of steel scrap, call for the use in steelmaking processes of a far bigger proportion of iron than was formerly the case. In consequence, a number of units which used to operate the cold metal process of steelmaking have been, are being, or are about to be converted, by the addition of coke ovens and blast furnaces, into integrated works operating the hot metal process. Appleby-Frodingham which is now the largest integrated steelworks in the British Commonwealth, has always had blast furnaces, but the post-war extensions have been influenced by the same general considerations as those elsewhere, together with a number of factors peculiar to the company.

Plant Modernisation

On the steelmaking side, a new Frodingham melting shop was put into operation towards the end of 1947. This consists of two 300–350-ton basic open hearth tilting furnaces, and one 600-ton active mixer. The furnaces are fully instrumented and fitted with automatic linkage between roof temperature and fuel flow, fuel flow and chimney damper control, and air/fuel ratio control. The mixer also has linkages between fuel flow and air supply, and furnace pressure and chimney damper. Roof temperature is recorded. Originally the furnaces were fired with mixed blast furnace and coke oven gas. When increased coke oven gas became available in 1953 with the introduction of new ovens, it became necessary to fire certain steel furnaces with coke oven gas mixed with creosote pitch. This gave important increases in output, and in 1953 the ingot production of the Frodingham shop exceeded 300,000 tons out of a total of 1,022,121 for the works as a whole. During 1947 also, 'R' furnace came into operation in the Appleby melting shop. Similar in design to the Frodingham furnaces, it is also fired with coke oven gas and creosote pitch.

The Frodingham section mills, built originally in 1888, and modernised from time to time in the intervening years, provide an interesting example of organisation in reconstruction work, as considerable changes have been made in the post-war period without any interruption of production. A new electrically driven 42-in. cogging mill went into operation in May, 1948, on a site adjacent to the existing train, and the electrification and re-siting of the 3-stand 32 in. section mill was completed during the two-week stop period in September, 1949. Other changes include the replacement of roller tables, galleries, etc., in the 32 in. mill; the provision of an ingot preheater, three soaking pits, and a bloom reheater; and new buildings and various service facilities.

In 1946–47, it was decided to commence rolling in the Appleby plate mills stainless steel ingots made by Samuel Fox & Co., Ltd., and this necessitated modifications to the 10 ft. normalising furnace already in existence, and the construction of a plant for acid pickling and buffing the finished plates. A section was added to this in 1952, which permits phosphoric acid pickling of plates and sections in ordinary constructional steels. In order to remove the rolling hardness from these plates, a continuous roller hearth stress relieving furnace fired by blast furnace gas has been installed. It is 204 ft. long and is in line with a hot mangle, so that a soft flat plate results. The temperature can be increased to deal with plates requiring to be normalised.

The 66 coke ovens which came into operation in 1939 are still working satisfactorily, and a further battery of 66 ovens, also of the Koppers type, commenced coke

production in December, 1951, bringing total output up to 11,650 tons/week, about half the total requirement of the plant. The total coke consumption is not expected to increase materially with the increased iron output of the new blast furnaces, because of the reduced requirement per ton of iron.

Other post-war developments include the provision of new central engineering workshops; a new pit arch plant; and a central refractory crushing plant. In anticipation of increased iron production, there has been a 50% increase in pig casting machine capacity with the addition of a third strand to the two already in existence.

The Problem behind Seraphim

Without doubt the most interesting feature of the Appleby-Frodingham post-war reconstruction is what is known as the Seraphim project. It comprises two new blast-furnaces and ancillary ore preparation and sinter plant which, together with turbo-blowers and the 2,000,000 gal./hr. cooling tower, are designed to produce 600,000 tons of pig iron each year. The name "Seraphim" is derived from the plant, the contractors and the designer: *S*outh ironworks *E*xtensions; *R*oss Engineers, Ltd. (primary and secondary crushers); *A*shmore, Benson, Pease, Ltd. (blast furnaces); *P*arolle Electrical Plant Co., Ltd. (blowing equipment); *H*ead Wrightson & Co., Ltd. (gas cleaning and sinter plants); and *IM*, the first two initials of Mr. Kemp, chief designer at Appleby-Frodingham.

At the initiation of the project, pig iron production was around 900,000 tons per annum, and it was desired to increase this figure to some 1·25 million tons. It was also very desirable to abandon some of the older and somewhat obsolete plant then existing. It was known that the required tonnage could be attained quite easily by the building of two large blast furnaces, and the retention of two built in 1939. Furnace practice and experience over many years indicated that, under certain favourable conditions, it would be possible to obtain a greater tonnage of iron from a blast furnace smelting home ores than had hitherto been possible.

Iron is produced at Appleby-Frodingham from a mixture of two types of home ore—Lincolnshire and Northamptonshire ironstones—both of low iron content and containing, respectively, appreciable amounts of lime and silica. By virtue of this fact a 2 : 1 mixture results in a self-fluxing burden. Lincolnshire iron production is, of course, based on the local ironstone, which is obtained by open cast working, and since the beginning of the current century Scunthorpe has been prosperous because of the ability to convert the low grade ironstone into the steel products so necessary to our present civilisation. During this period, however, there has been a gradual deterioration in the quality of the ore. The South ironworks was built before the war and incorporated crushers, ore-bedding plant and sinter plant, as well as two large blast furnaces, so that the deteriorating ores could be handled. By 1945, the furnaces were demanding yet easier burdens than the ore preparation plant could supply, and the management and heads of the Company were becoming more and more concerned and apprehensive about the technical difficulties involved in this deterioration.

The sulphur content of the Lincolnshire ore had increased so that the average deliveries were of the order of 0·4%, and at the same time there was a reduction in iron content of about 1%—an appreciable decrease in a total iron content of barely 20%. During the same period the quality of coking coals and their sulphur content had also changed for the worse. In 1939, the sulphur load at the Appleby-Frodingham furnaces was 42 lb./ton of iron, but by 1946, this figure had increased to 52 lb./ton of iron.

Screening section of primary crusher building.

Furthermore, the physical quality of both the local and Northants ores had changed. The intensification of quarrying with the use of bigger and heavier machines, and the gradual introduction of underground working, had led to a considerable increase in the amount of fines in the ore, and it seemed likely that these trends would continue.

By 1951, with the existing mining and ore preparation processes, the arising fines comprised some 50% of the total ore intake, so that, to achieve a clean lump ore burden, half the incoming raw material would have to be discarded, a procedure that no industry could afford. Further processing was, therefore, necessary to fit the extracted fines for use in the blast furnace, and sintering appeared to present the only satisfactory solution. At that time little was known of the fundamentals of sintering, particularly of British ores, as the high volatile content (moisture and carbon dioxide) and the presence of up to 20% lime in the finished sinter made home ore sintering a very different proposition from the sintering of rich ores.

Briefly, the position when the Seraphim project was conceived was as follows:

(*a*) The economic advantages of the big blast furnaces had been demonstrated.

(*b*) These advantages could only be exploited to the full if the furnaces were provided with better materials than had hitherto been possible.

Screening end of tertiary crusher building.

(*c*) Coke quality was more critical with the big furnaces than with smaller units.

(*d*) The production of sinter suitable for the blast furnace demanded more elaborate plant than, at that time, existed.

(*e*) The advantages of sinter in the blast furnace burden were realised, but, because of the inability to produce a satisfactory sinter, had not been attained.

(*f*) Blowing power on a much more generous scale was necessary to secure higher rates of production. The possibility of using high top pressure operation was investigated very fully and decided against, although it was realised that it would be necessary to blow a furnace at much higher pressures than had been the case.

(*g*) The projected future production of increased tonnages of pig iron from fewer units obviously emphasised the importance of maintenance in all its angles.

All these problems, although interdependent, could be, and were, tackled separately.

Furnace Size.

The two furnaces built at South ironworks in 1939, and now known as Queen Mary and Queen Bess, were originally of 22 ft. hearth diameter, but by the use of carbon refractories in the hearth and bosh, they were enlarged within the existing shells to 25 ft. together with an increase of approximately 10% in volume. The first of the enlarged furnaces was blown in during 1951 and it quickly demonstrated that it was capable of much greater production, with no increase in coke rate, than had been obtained with a 22 ft. furnace. Accordingly, the two new Seraphim furnaces were designed at 27 ft. hearth diameter, to which the Queen Anne furnace was built. The design for the second furnace, Queen Victoria, was changed to 28 ft. 6 in. hearth diameter in view of the encouraging results from the 25 ft. furnaces.

Ore Supplies.

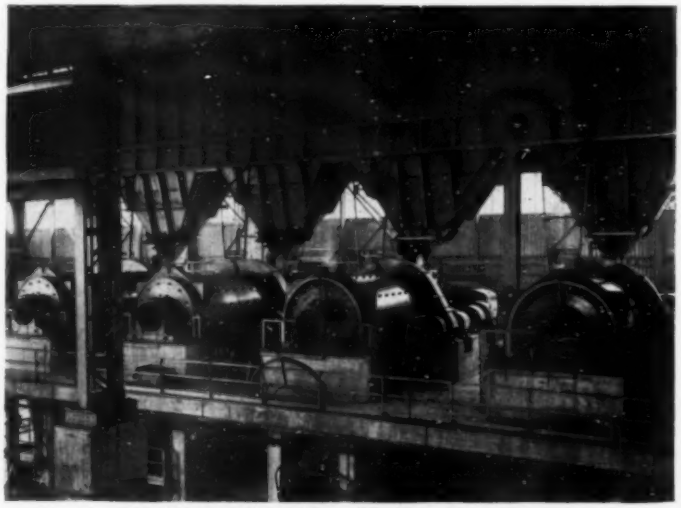
It was known that the future ore supplies would be wholly iron ores from the Frodingham and Northants fields, as all past experience indicated that the smelting of imported foreign ores was unlikely to be economic under any conditions obtainable in the foreseeable future. The Frodingham and Northants ores were estimated to have a continuing average analysis of

	Fe%	SiO_2%	CaO%	Al_2O_3%	MgO%	S%
Frodingham	30.0	9.0	20.0	4.0	1.5	0.40
Northants	30.0	18.0	2.0	6.0	1.0	0.15

It appeared that, in order to produce the desired tonnage of pig iron, it would be necessary to load into the plant some 65,000 tons of Frodingham ore and 35,000 tons of Northants ore each week. This mixture gives a slag volume of 26 cwt./ton of iron produced. A great deal of experimental work has been devoted to finding methods of reducing this slag volume by concentration of the ores. It is possible to concentrate the Frodingham ore by an oxidising roast followed by a magnetic separation. Essentially, this consists of discarding the lime content of the ore, but unless concentration of the Northants ore could be achieved there would be little point in it, because of the lime necessary to flux the silica of the Northants ore.

In the Northants ore the iron is present largely as the mineral chamosite, and it was confirmed that it was impossible of concentration by any of the known concentration processes. It followed, therefore, that the Seraphim plant would have to be designed to deal with the very high metallurgical load arising from the high slag volume, and once chemical improvement of the burden was realised to be unattainable, even greater emphasis was placed on improved physical conditions of the burden.

About the same time, full scale trials had indicated the very real advantages attainable by the smelting of 100% sinter in the blast furnace. Although sintering improves

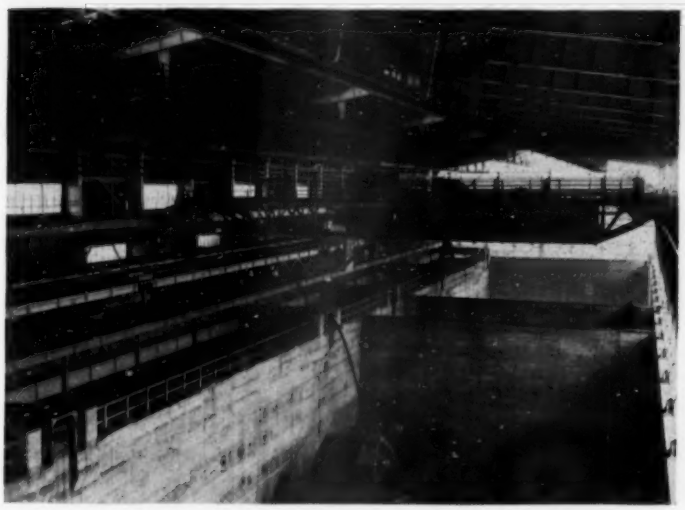


Coke-grinding plant showing rod mills.

the iron content of the charge, it does not do so by the reduction of slag volume. It only removes the volatile content of the raw materials, but it was found that this had a profound influence on both production and fuel rates of the blast furnace. Although the improved fuel rate may be partly offset by the use of fuel in the sinter plant, the latter is coke breeze, which is useless in the blast furnace, and not metallurgical coke.

A further important advantage of the high sinter burdens followed the appreciable reduction in the amount of sulphur charged to the blast furnace. In the sinter plant, about 70% of the ingoing sulphur is driven off. In addition, the reduction in coke consumption accompanying the use of nothing but sinter in the blast furnace reduces the sulphur load arising from that source.

It was decided, therefore, that the Seraphim plant would be designed to feed the furnaces exclusively with sinter, although the arrangements should be sufficiently flexible to permit the use of ore burdens if necessary.



Sinter materials storage building, showing shuttle conveyors.

Coke.

Experience with the 22 ft. and 25 ft. furnaces demonstrated the need for the coke to give a figure of at least 85 for the 1½ in. shatter test. To achieve this on the ordinary mixture of South Yorkshire coals is a matter of some difficulty, and a considerable amount of research was carried out on this problem. Pilot ovens were built at each of the Company's coking plants and at Appleby-Frodingham alone more than 600 tests were made in efforts to find improved blends and carbonising methods.

The coke oven plant was increased from 66 to 132 ovens in 1952, and arising from experimental work more extensive grinding arrangements were installed, so that the degree of crushing was increased from 78% to 85% below ⅛ in. This improved grinding, together with the addition of small amounts—about 5%—of low-volatile Welsh coal, resulted in an increase in the shatter strength of the coke from 88 to 90, although the Welsh coal itself is completely non-coking.

This improvement in coke quality removed one of the biggest fears the blast furnace operators had when considering the future production of pig iron in large furnaces. With coke from Appleby-Frodingham and the associated plants at Orgreave and Brookhouse, the company should be virtually self-supporting in regard to this vital material, so ensuring complete control over supplies and quality.

Sinter Quality.

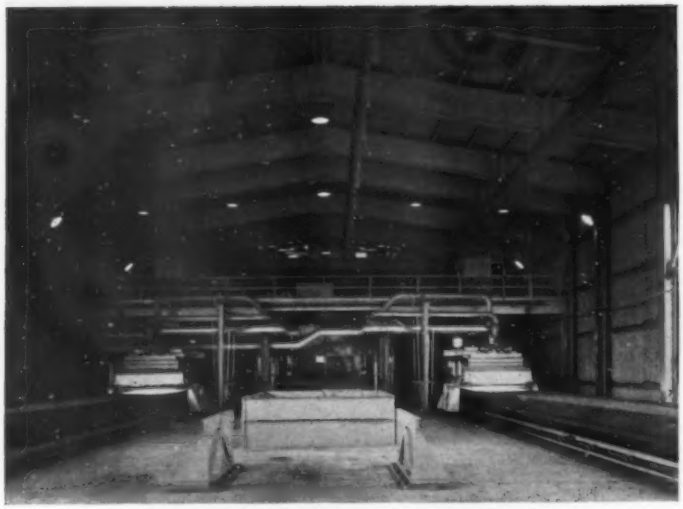
The problem of sinter quality was being tackled at the same time as work was going on in regard to coke quality. Although it was possible to lay down with fair accuracy the blast furnace requirements in the way of coke quality, it was impossible to do the same with regard to sinter quality. Many undesirable properties of sinter were known, one of the main problems being the mechanical breakdown arising from the presence of free lime in the fossil shells of the Frodingham ironstone, aggravated by the necessity of using water to cool the sinter after manufacture.

It became clear that the influence of lime was minimised if the raw materials for the sinter plant were crushed wholly to —¼ in. This opened up a new concept: it was now established that the blast furnace did not like material smaller than ¼ in., whilst the sinter plant demanded material less than ¼ in. It was, therefore, necessary to introduce a third stage of crushing in addition to the primary and secondary crushing already practised. As it was intended to operate the furnaces on 100% sinter, it followed that it would be necessary each week to reduce about 100,000 tons of ore to —¼ in.

The cooling of sinter by water had resulted in the production of a considerable amount of dust objectionable to the blast furnaces, and no satisfactory method of air cooling had been evolved. Fundamental research indicated possible methods of cooling sinter by forced draught, and the value of air cooling was demonstrated both in the laboratory and in full scale tests, prior to its incorporation in the Seraphim plant.

Initial operating difficulties with an earlier sinter plant installation led to intensive research and experiment in connection with air requirements for the sintering process. Arising from this work, it was decided to be much more generous in the provision of both grate area and air supply in the plant being designed, and an important side-line of the research was the development of additional instruments for the control of the process. It was shown that many of the manufacturing difficulties could be offset by increasing the circulating load of the process from the usual 15% to 40%, or even 50%: the design had, therefore, to cater for this.

Although future operation was intended to use very little lump ore, it was realised that on occasion it might be desirable or necessary to depart from 100% sinter practice. Experience had indicated the difficulties in the way of efficient screening of the ores, and, accordingly, very large screen area was allowed for, to ensure that any lump ore being used was as free from adhering fines as possible. Double screening was planned, and equipment was requested to permit charging separate sizes of ore and sinter to the furnace. This meant the installation of screens before the blast furnace lines.



Two of the Seraphim sinter strands.

Blowing Power.

On the ore burdens used previously, it was impossible to obtain satisfactory blast furnace operation at high blowing pressures, e.g., the 22 ft. furnaces when using 33% of sinter would not give good results if the blowing pressure exceeded about 16 lb./sq. in. On the other hand, experience with the 25 ft. furnaces on 100% of sinter showed that good operation was possible up to pressures of 22 lb./sq in., which was the maximum pressure obtainable from the existing gas blowers.

All evidence indicated that this trend would continue, so blowing plant was asked for capable of delivering a satisfactory volume of air at pressures up to 30 lb./sq. in. It may be mentioned here that the 27 ft. Queen Anne furnace has been operating very satisfactorily at a pressure of 28 lb. /sq. in.

Close investigation into the use of gas turbines for blowing had been carried out, but in spite of the many attractions of such equipment, it was finally decided to use orthodox centrifugal blowers driven by steam turbines. The deciding factor was to ensure completely reliable blowing plant, particularly when so many other features of original design were being incorporated in the project as a whole.

Maintenance.

As it was intended to concentrate iron making in fewer units, the necessity for a high standard of maintenance throughout the plant led to every consideration being given in new design either to reduce maintenance or to make it easier. Especially was the need for speedy relining of the blast furnaces borne in mind. Emphasis was also placed on the necessity for efficient means of signalling and communication within each section of the works.

Description of Seraphim Plant

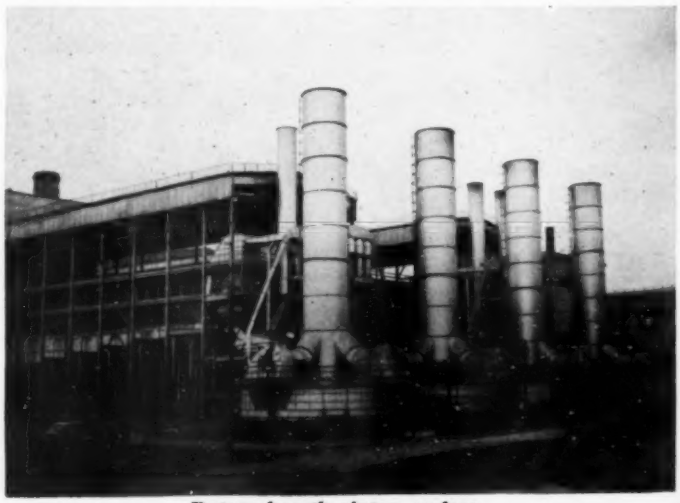
The 1939 project, which included the provision of the two 22 ft. hearth diameter blast furnaces, together with ore preparation plant (incorporating facilities for crushing, screening, bedding and sintering), and blowing and steam services, is known by the code name of Apex, and in the description of the Seraphim plant reference will be made to certain items forming part of the earlier scheme.

Ore Crushing Plant.

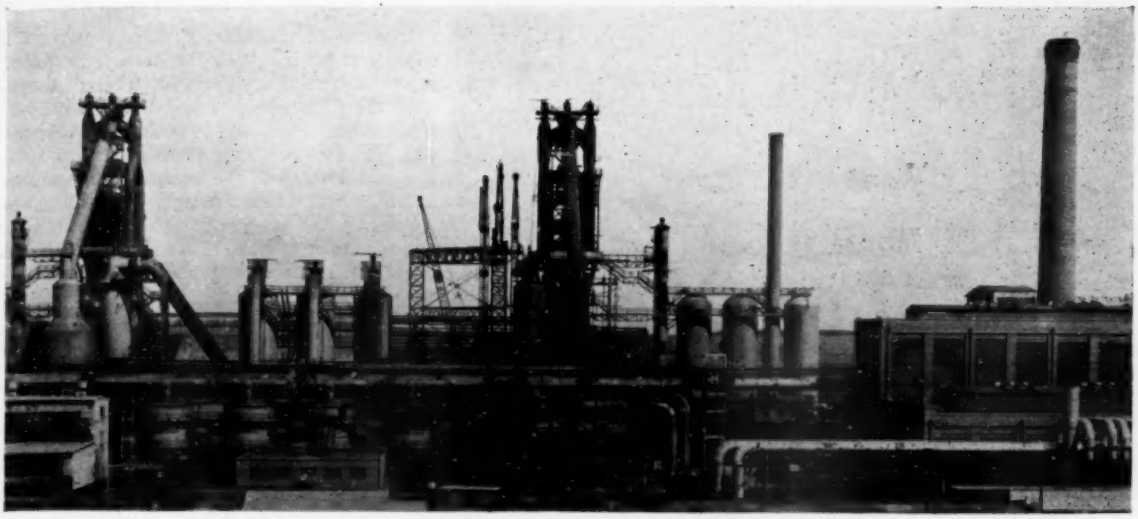
The No. 3 ore crushing plant, designed by Ross Engineers, Ltd., handles all the incoming ore from the Frodingham field at a rate of some 800 tons/hr., the Northants ore being dealt with by the Apex plant. The primary crusher, which is fed by an inclined car haul and tippler system, is a Hadfield two-roll crusher with 6 ft. diameter × 5 ft. wide rolls. The product from the crusher is handled by drop bar feeders operating in conjunction with two-roll grizzlies, and is separated into + 2 in. and — 2 in. fractions, the former passing to the secondary crushers.

These comprise two 5½ ft. symons cone crushers, each capable of handling 350 tons/hr. The product from the secondary crushers, together with the —2 in. material from the primary crusher, passes to the primary screens, which consist of two banks of vibrating screens, each consisting of two screening decks, 14 ft. × 6 ft., arranged in series. The undersize (— ¾ in.) material passes to the Seraphim tertiary screening and crushing plant to provide the Frodingham ore supply to the Seraphim sinter plant, whilst the oversize (+ ¾ in.) goes to the Apex bedding plant to provide Frodingham ore to the Apex section.

All the fines destined for use at the Seraphim sinter plant are delivered to the tertiary crushing building. Both the Northants ore from the Apex drying plant and the Frodingham ore from the primary screens are first screened to remove the —¼ in. material before passing the remainder into hammer mills for reduction to ¼ in. The screens for the Frodingham ore are gas heated to prevent blinding when the ore is wet. There are three hammer mills for each class of ore, all of the Pennsylvania Dixie type made by Fraser & Chalmers, Ltd. Each has a capacity of 120 tons/hr. and is fitted with 3 rows of 21



Rotary hearth sinter coolers.



The Queen Anne (left) and Queen Victoria blast furnaces with the new blower house on the right.

hammers. A dust extraction system covers the screen and mill area, and extends into the sinter material storage building in which the crushed fines are delivered. Dust is extracted by means of Van Tongren cyclones installed by Buell Combustion Co., Ltd.

Sinter Plant.

Head Wrightson & Co., Ltd., were the contractors for the sinter plant, two strands of which went into operation in June of this year and two in July.

The sinter material storage building is 400 ft. × 100 ft. and has three bays for stocking respectively, 17,000 tons of Frodingham fines, 17,000 tons of Northants fines, and 2,000 tons of crushed coke. Of a line of bins running parallel to the storage bays, four of 90 ton capacity are allocated to Northants ore, four similar ones to Frodingham ore, and six 12 ton hoppers to crushed coke. All these are fed from the incoming belt systems or from stock.

Coke breeze is processed in four rod mills before delivery to the storage building. The coarse breeze is handled through a track hopper to a screen situated over a surge bunker, which has four outlet necks through which the oversize (+ $\frac{1}{8}$ in.) is fed by vibrating feeders into four Newell rod mills. The mills are 7 ft. 6 in. in diameter × 14 ft. long and each contains 10 tons of mixed 3 in. and 3$\frac{1}{2}$ in. diameter rods. The output per mill is about 10–12 tons/hr. when crushing to $\frac{1}{8}$ in., the product passing to the storage building along with the screened-out —$\frac{1}{8}$ in. material.

The feed from the ore bins is controlled by 9 ft. diameter variable speed rotating tables with plough discharge, and the coke bin discharged by variable speed belt feeders. These feeds may discharge into either of two gathering belts, each of which start the feed system to a pair of sinter strands.

A typical sinter mixture comprises 40% Frodingham fines, 14% Northants fines, 40% return fines and 6% coke; and a typical sinter analysis is: Fe, 36·0%; SiO_2, 17·0%; CaO, 18·5%; and S, 0·2%. Each feed system has a Newell primary mixer consisting of a drum rotating at 3·4 r.p.m. and containing two paddle shafts rotating at 148 r.p.m. and 120 r.p.m.: water is added through spray pipes. Each mixer has a capacity of 370 tons/hr., the product passing alternatively into two surge hoppers, each of which then supply a single sinter strand. The hoppers each have a capacity of 80 tons, and the feed from them is controlled by variable speed tables with plough discharge. Each hopper may discharge into either one of two mixers which are similar in design to the primary mixer but slightly smaller, having a capacity of 186 tons/hr. The amount of water added, which controls the permeability of the sinter bed, is adjusted by electrically operated valves from the control room. The feed from the mixers is distributed onto the strands by a swinging spout.

There are four sinter machines or strands, of McKee —Head Wrightson design, each 6 ft. wide and 168 ft. long with 28 windboxes. Each strand contains 191 cast iron pallets, 6 ft. × 2 ft. × 14 in., with detachable cast steel ends and grease-packed and sealed wheels. Ignition is effected by two rows of burners, in a brick-lined hood, fired by mixed blast furnace and coke oven gas, and the output of sinter is 60 tons/hr./machine.

The windmain is brick lined and incorporates two expansion joints, and the Howden fans are of the double-inlet type with back-swept blades. Driven by a 2,210 h.p. motor, each fan has a capacity of 300,000 cu. ft./min. of air at 26 in. w.g. suction and a temperature of 350° F. Vanes housed on each side of the impeller are controlled hydraulically by the machine operator. The exhaust from the fans is carried through underground flues to a 150 ft. high chimney, one to each pair of strands.

The discharged sinter coke passes through a crusher onto a vibrating screen. The oversize passes through a bunker into a vibrating feeder from which it is fed onto the Lurgi sinter cooler. The latter consists of 32 disconnected pans which travel round a circle below a stationery air duct. The pans are louvred grates 5 ft. long × 5 ft. wide, and provide a cooling area of 560 sq. ft. Each pan makes a complete curcuit, after which it passes over a dip rail, where the cooled sinter is discharged into a hopper, from which it is fed onto a gathering belt for delivery to the high line bunkers. The speed of rotation can be varied, but is normally about 3 rev./hr. Air is drawn through the sinter cooler into the duct by means of three suction fans, each rated at

74,000 cu. ft./min. at 2 in. w.g. and 130° C.: the fans discharge into a common central stack. Each cooler has a capacity of 60 tons/hr.

The undersize material screened out by the sinter screen passes through the feeder into double paddle mixers where water is added to cool it, before being fed by belt to a 2,000 ton surge bin, ready for discharging into the sinter mixture supply by rotary feed tables.

At the various points in the crushing and sintering plant where dust can arise, extensive dust extraction plant is installed.

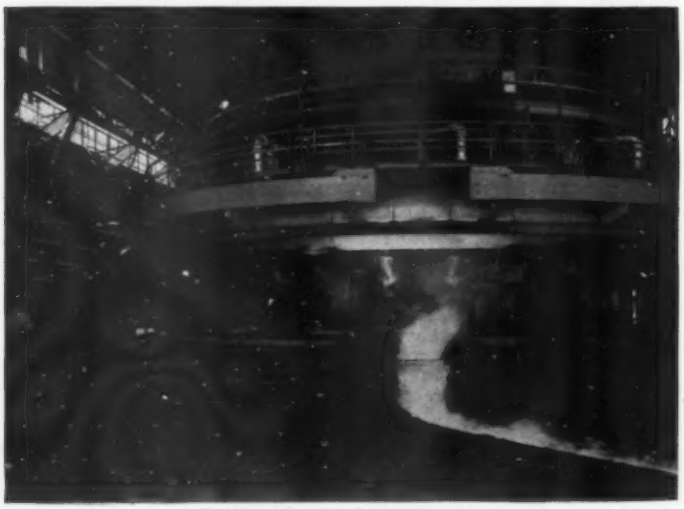
Blowing Plant.

The blowing plant consists of four Parsons steam turbine driven centrifugal blowers working at a steam pressure of 425 lb./sq. in. and a temperature of 740° F. The blowers are rated at 75,000 cu. ft./min. of free air at 30 lb./sq. in. gauge pressure when running at 2,740 r.p.m. There are four Thompson Etaflo water tube boilers, which can be fired with blast furnace gas or oil fuel. They are each rated at 85,000 lb./hr. of steam at 450 lb./sq. in. pressure and a temperature of 760° F. The feed water is supplied from three Aiton triple effect P & B evaporaters, and Weir electrically operated boiler feed pumps with steam driven standbys are provided. Ring main steam and feed systems have been adopted.

The plant is housed in a steel framed brick building, without any dividing wall between the boiler and blower sections. As the level on which good load-bearing material existed was about 20 ft. below the works ground level, it has been possible to place the boiler firing floor and turbo-blower floor at the works level, which is a convenient arrangement.

Each blower delivers into a header (placed just outside the blower house wall) on which there are four 42 in. electrically operated valves. The spindles of these valves protrude inside the house, so that they can be hand operated in an emergency. The arrangement of blast mains permits any one of the blowers to blow any one of the four furnaces. Great flexibility has been provided in the layout of the mains, to allow for expansion.

The Parolle Electrical Plant, Co., Ltd., was the main contractor for the blowing plant and ancillary equipment.



Casting Queen Anne furnace.

Blast Furnaces and Stoves.

The general layout of the blast furnaces, stoves and high line follows that for the Apex furnaces, Queen Mary and Queen Bess. The ancillary parts have been enlarged in keeping with the furnaces, and the distance between furnace centres has been increased to 60 ft. to accomodate extra slag and iron ladles. This provides a large cast house, and a novel feature is the assembly of the staff and operator offices and welfare rooms, with the instrument house in the centre, along one side of the building between the hoist houses. Improved clay gun houses have been provided, and walkways alongside the crane gantry give safer access.

Though high top pressure operation has not been adopted, the furnaces and gas cleaning plant have been designed so that it can be introduced if desired.

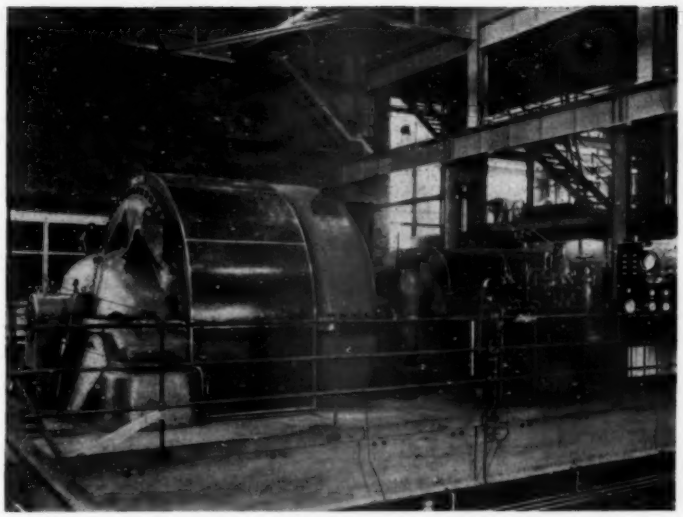
Apart from the difference in hearth diameter referred to earlier, the Queen Anne and Queen Victoria blast furnaces are almost identical. The hearth diameter of the Queen Anne furnace is 27 ft., the bosh diameter 30 ft. 3 in. and the effective volume is 42,372 cu. ft., the corresponding figures for the Queen Victoria furnace being 28 ft. 6 in., 31 ft. 9 in., and 44, 351 cu. ft. Common dimensions include: small bell diameter, 7 ft.; large bell (53° angle) diameter, 15 ft.; height from taphole to top of hopper, 100 ft. 2 in.; height from ground to top platform, 121 ft. 3 in.; and height from ground to bleeders, 224 ft. 3 in. Each furnace has four 5 ft. 8 in. diameter gas offtakes, two 7 ft. 6 in. diameter gas uptakes, and one 9 ft. diameter gas downcomer. The hearth bottom is formed of 5 ft. 4 in. of carbon over 10 ft. of firebrick, and the hearth and bosh walls are also constructed of carbon: the stack is of firebrick. The hearth is cooled by 23 cast iron stave coolers, and the tuyere belt by 103 plate coolers. There are three rows of 27 cigar coolers and the bosh jacket is spray cooled, the total water supply to each furnace being 4,500 gal./min. The hearth tuyeres number 18 (16—15×17 in. and 2–18×3½ in.) and there are 9–11×5 in. bosh tuyeres and 3–2½ in. diameter slag tuyeres. Because of the large amount of slag produced, each furnace has three slag notches. The iron runners have four spouts per furnace, teeming into 70 ton ladles, and the slag runners ten spouts per furnace teeming into 20 ton ladles. The taphole is closed by a Bailey electric plunger type clay gun with a capacity of 13 cu. ft. The supply and erection of the two blast furnaces and ancillary equipment was the responsibility of Ashmore, Benson, Pease & Co., Ltd.

The stock house extension for the two furnaces is 860 ft. long, with 68 ore and sinter bins having a total capacity of about 5,250 tons, and four coke bins of total capacity 500 tons. Near the end of the extension, overhead bins which discharge into transfer cars are provided for receiving sinter from the Seraphim plant and purchased coke. Both are brought up by conveyors and coke breeze is screened out here. There are two ore transfer cars of 50 tons capacity, two coke cars of 30 tons capacity, and three double compartment scale cars of 225 cu. ft. capacity per compartment.

Each furnace has double-skip charging

gear with a skip capacity of 240 cu. ft. The drive for each hoist comprises two 200 h.p. Metropolitan-Vickers MX mill type force ventilated motors fed from a motor-generator set with Ward Leonard control. In the event of failure of one motor, the hoist can be operated by the other one at reduced speed.

The Igranic charging control is fully sequenced, and automatic coke charging is provided, the charge being measured by weight or by volume, as desired. The order for charging coke and ore can be preset on the charging control panel for each of the two ten skip cycles. When the skip arrives at the pit for an automatic coke charge, the hopper gate thruster operates, and dumps the previously measured charge of coke into the skip. When the hopper gate closes, the skip hoist switch operates, and the coke screen starts refilling the hopper in readiness for another coke charge. The screen is stopped when either: (*a*) the Pooley weigher dial pointer reaches the preset figure; or (*b*) the coke in the hopper reaches the electrode, depending on which method of measurement has been selected.



Turbo-blower "A."

The large and small bells are pneumatically operated, the supply of air being controlled by motorised valves, whose operation is governed by the bell sequence section of the charging control panel. Each McKee distributor is driven by a 25 h.p. motor, and a changeover switch on the distributor panel enables the distributor to operate after either the large bell or the small bell. The number of dumps at each distributor position can be preset up to a total of ten, and each operation of the distributor advances it through 60°. Two stock level indication rods, diametrically opposite each other, are provided for each furnace. They are under the control of 1¼ h.p. torque motors, the rods being withdrawn before the operation of the large bell. Automatic withdrawal of the rods is also provided when the burden level falls below 14 ft. Indication of stock level is transmitted to the cast house, the snort station and the skip pit.

The main instrument room, situated close to the manager's office, is common to both furnaces, and contains records of the blast flow, measured at the turbo-blower inlet and transmitted electrically; of the automatically controlled hot-blast temperature; and of pressure; stockline level; in-wall temperature at six points round the furnace, 8 ft. 6 in. below the "full" level; top gas temperature; and top gas pressure. A special instrument has been developed for each of the Seraphim furnaces to check the operation of the automatic charging control. It takes the form of a two-pen recorder; one pen with centre zero records the angle of rotation of the McKee distributor in both directions, the pen returning to zero when rotation ceases. The second pen makes a mark on the chart every time a skip travels up the hoist.

Instruments of value to the man-on-the-job have also been provided. The cast house control room, which contains the clay gun controls, three gas bleeder winches and snort valve operating gear, has also an instrument panel fitted with top gas pressure recorder and indicators of top gas temperature, blast flow and pressure, and stockline level, together with the panel of switches and indicating lamps comprising the signalling system to blowers and gas cleaning plant. In addition to the normal purposes, the top gas pressure recorder plays an important part in the control of shutting blast off the furnace and putting it on again.

The furnaces have each three 22 ft. 6 in. diameter × 100 ft. high hot blast stoves with McKee checkers of 1 $\frac{15}{16}$ in. square opening giving a heating surface of 160,000 sq. ft. per furnace. The gas burners are of the Freyn pressure type with retractable body, and the hot blast temperature is controlled by cold air admission though butterfly valves with temperature control. The control of the stoves is a repetition of the method adopted on the Apex plant, the reason being the excellent condition of the six stoves after 15 years service without any repairs to brickwork, which is attributed to the care taken to prevent excessive temperatures of the domes and waste gas outlets, the allowable limits being 1,100° C. and 200°C, respectively. The dome temperatures will again be automatically limited by setting the stove burner combustion regulators to give an air-to-gas ratio of approximately 1·4 to 1, and the stove minder will be instructed to take gas off when the waste gas reaches the temperature limit which has been set with a view to maintaining high thermal efficiency.

Gas Cleaning Plant.

The gas cleaning plant, the responsibility of Head Wrightson & Co., Ltd., consists of the conventional dust catchers and three McKee type gas washers, feeding into a common "semi-clean" gas header, whence the gas passes in parallel through five Research Corporation wet tube electrostatic precipitators into the clean gas header. The middle washer of the three is a stand-by for either blast furnace. Both washers and precipitators are equipped with quick acting goggle valves, so that positive and safe shut off can be obtained with negligible risk of gas leakage into any isolated section. If the efficiency of cleaning is to be optimum, it is practically essential to ensure that the gas flow at any time is evenly distributed through the precipitators. This has been done by providing in the clean gas outlet of each precipitator a measuring orifice and an oil hydraulic remote-controlled butterfly valve, so that the plant attendant can

readily make the adjustment necessary to ensure even distribution. This provision will also enable the plant engineer to detect more readily the incipient accumulation of dirt in the semi-clean inlet to any particular precipitator.

The cleaning plant has been designed to handle a gas quantity of 6 million cu. ft. /hr. from each furnace, and to clean the gas to a dust concentration not exceeding 0·005 grain/cu. ft. when the concentration in the dirty gas entering the washers is 7 grains/cu. ft. The washers are 20 ft. diameter × 65 ft. high and are fitted with three banks of tiles and one bank of rings. Water from the washers passes in concrete flumes to three clari-flocculators where the solid matter is removed. The precipitators are 23 ft. diameter and each contains 300 8 in. diameter × 15 ft. long tubes.

Since there is no " boosting " of pressure involved in the cleaning process, the top gas pressure at the furnaces is the sole motive power for ensuring the flow of gas through the cleaning plant, and subsequently to the ironworks consumers and the existing gasholder. The general level of pressure in the clean gas trunk main is about 20 in. w.g., as compared with 30–35 in. w.g. in the dirty gas inlet to the washers. The Seraphim plant consumers of gas include the four boilers for the blower plant; the hot blast stoves; and the sinter plant ignition hoods.

Acknowledgment

We are indebted to the Appleby-Frodingham Steel Company and to the United Steel Companies, Limited, for the illustrations used in this article.

PERA Mobile Demonstration Unit

THE mobile demonstration unit of the Production Engineering Research Association begins this month its first tour of the country, during which it will visit engineering firms by appointment. Following its appearance at the Scottish Industries Exhibition, it will make calls on individual firms in the Glasgow area before proceeding to Leeds via Newcastle.

The unit consists of a small cinema and lecture theatre to seat 24, a demonstration and exhibition room, and an extension for site erection. The former is used for showing films, made at P.E.R.A. and elsewhere, which can assist firms to secure improved production, and for talks, illustrated by lantern slides, showing production techniques recommended as a result of P.E.R.A.'s practical researches.

Demonstrations and discussions, with the aid of machines, components, models and diagrams, of recommended techniques for tool grinding; drilling, tapping, turning, grinding, etc., of various materials; blanking; deep drawing; impact extrusion; thread rolling; and other common production operations; are mainly for the benefit of shop floor personnel in firms where the management require the recommendations of P.E.R.A. to be adopted with the minimum delay.

The exhibition is arranged to give a general picture of the activities and services of the Association. The nature and range of P.E.R.A.'s research programme is outlined, and examples are given of successful applications in industry, whilst the scope of the technical enquiry service is indicated by examples of typical problems and requests dealt with in the fields of machining, presswork, assembly, materials handling, inspection, finishing operations, etc. Also illustrated is the liaison service, whereby engineers from P.E.R.A. visit member firms, when necessary, to consider production problems on the workshop floor, and assist in the application of P.E.R.A. research results and information services. Other aspects of the work featured include the abstract and reprint service, and educational activities such as refresher courses and training schemes.

A view of the complete. unit.

A demonstration in progress.

The cost of equipping and operating the mobile unit throughout the country is being met by a special grant received through Conditional Aid and the Department of Scientific and Industrial Research.

Nu-Swift Order

NU-SWIFT, LTD., announce the receipt of the first order for their Chloro-Flash Extinguishers for use in aircraft of the Royal Danish Air Force. Charged with the new fire fighting chemical, chlorobromomethane, which, mixed with carbon dioxide, is held under pressure, Chloro-Flash Extinguishers are particularly effective on extra-hazardous fires.

Corrosion Control by Anodic Protection

By C. Edeleanu, M.A., Ph.D.
Firth-Brown Research Laboratories, Sheffield.

Cathodic protection has been widely applied as a means of preventing the corrosion of certain metals because it is almost foolproof. Anodic protection, on the other hand, is only applicable under special conditions but, as will be shown in this article, it is capable of spectacular results, such as the protection of stainless steel used as a boiler for sulphuric acid solutions.

IT has long been known that the corrosion of certain metals can sometimes be prevented by cathodic polarisation, and this fact has frequently been used in practice[1]. Galvanising is one of the best known examples of an industrial application of the cathodic protection of iron under atmospheric or " tap water " conditions, but there are numerous other processes which depend on this principle.

It has also been known for a considerable time that anodic polarisation can prevent corrosion by inducing passivity[2], but this type of protection is not often used in practice. It seems probable that anodic protection has not appealed to the practically minded because it is only applicable under special conditions, and there is a feeling that anodically induced passivity is a laboratory curiosity. In other words, anodic protection is not foolproof, and if a system is not understood, the application of an anodic current could easily lead to an increase in corrosion rate rather rather than a decrease.

Cathodic protection is, however, as near foolproof as can be in the case of iron in near neutral solutions, but it can sometimes increase the corrosion rate of metals such as aluminium and zinc under certain conditions, and can also destroy the corrosion resistance of stainless steels in sulphuric acid.

Two of the main limitations of cathodic protection are that it is not applicable to acid conditions, except in the case of relatively noble metals and, secondly, it is not easily applied, even in neutral solutions, to those metals with oxides soluble in alkaline solutions. Anodic protection naturally cannot be expected to fill the whole gap left by cathodic protection. From the present experiments, however, it seems that anodic currents can prevent the corrosion of some metals and alloys on the acid side of the range for which they are at present considered suitable.

A complete theoretical explanation for anodic protection is difficult at the present stage, and there are many existing theories. One of these[3] has been discussed briefly in a recent publication, and since it is the one on which the present work is based, it is mentioned in preference to others. The basic assumption made is that passivity depends on the presence of an insoluble oxide film, and that the solubility of the film in acid, in turn, depends on potentials. It has been found, for example, that with stainless steels the film becomes relatively soluble when the potential is sufficiently high to allow the oxidation of the chromium in the film to the hexavalent state, and there is evidence that the reduction of iron in iron oxide from the trivalent state to the divalent state can have a similar effect.

Whether or not the above theory is correct, the fact remains that there is now an experimental method available for the study of anodic protection, and that the method has, as described below, been applied successfully on a pilot plant scale under very severe conditions.

Method of Study

There are various methods of study, but the one which has proved most valuable to date depends on the use of a potentiostat*. With this instrument, it is possible to establish whether there is a range of potentials over which a metal or alloy is passive in a given solution, and whether this range extends to values which could be applied in practice.

The principle is that the specimen is immersed in the solution under investigation and its potential is measured against a standard electrode such as a calomel half cell. If the potential of the specimen is not the one at which the instrument is set, a polarising current is automatically supplied by the potentiostat, via the specimen and a third inactive electrode such as platinum, so that the potential is lowered or raised to the desired value.

The potentiostat, naturally, has not infinite sensitivity and the potential is, therefore, always slightly off the required values, but this does not matter at the present stage, since great accuracies are not necessary. It must also be remembered that the potential measured against the calomel electrode is sometimes a compromise potential, since not all the specimen is at the same potential. This arises when currents flow over the surface of the specimen, but the difficulty is only met when the specimen is being corroded—for instance, by pitting or intercrystalline corrosion. There is no difficulty, therefore, in finding with reasonable accuracy the range of potentials over which there is virtually no corrosion, and this, for the present, is our main interest.

There are various possible ways of determining the corrosion rate of a specimen when it is being maintained in this manner at a constant potential. The obvious method is to keep it in the solution for a sufficiently long period to be able to detect a weight loss, and a series of results obtained in this manner has already been published[3].

The main difficulty is that at low rates of corrosion the accuracy is poor, especially if there is film " growth " as well as dissolution. Furthermore, it is not easy to study the effect of time, especially during the important initial period. Some of these difficulties can be overcome by analysing the solution in which the test is being carried out, at various intervals. It is perhaps even better to measure and record the current passing through

* The potentiostat is an instrument which maintains a working electrode at any desired potential value, by controlled polarisation. There are various well tried circuits for potentiostats, but a purely electronic apparatus, described by Roberts[4], has been used in the present work and is believed to have many advantages.

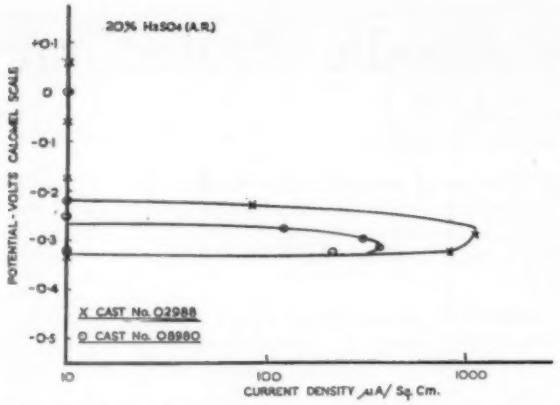


Fig. 1.—Potential/current density curves for two 18-8 Mo steels. Negative current densities and those smaller than 10 micro amps are shown on vertical axis. The potentials are on the saturated calomel scale.

the specimen during the test, since currents of a few micro-amperes, which correspond to minute rates of corrosion, can easily be measured. The difficulty with current measurements arises when side reactions such as the reduction of oxygen occur as well as the main corrosion reactions.

All the above difficulties can be overcome, where the labour is justified, if all three methods are used, and if microscopic examinations are carried out to ascertain that pitting, intercrystalline corrosion, etc. are not taking place.

Much of the labour involved in such experiments can be avoided when experience has been gained in a particular system, and, for instance, curves like those in Fig. 1 can be drawn in a matter of two hours. These results, obtained with two 18–8 stainless steels containing molybdenum of somewhat similar composition (Table I), depend on current measurements. The interpretation is not as simple as when the weight loss is also determined, but from the experience gained in other experiments under somewhat similar conditions, it is safe to assume that in both cases no appreciable corrosion should occur in 20% sulphuric acid, provided the potential is not allowed to drop below about −0·2 volt (saturated calomel). The relation between potential, current and corrosion rate is explained briefly in the appendix.

The curves, incidentally, also indicate that there is a slight difference of behaviour between the two steels, and that one, Cast 08980, can withstand a somewhat lower potential before the onset of corrosion than the other. This should be reflected in conventional corrosion tests, and in Table I are given the weight losses, in g./sq. cm./day, of emeried specimens corroding in sulphuric acid. Cast 08980 is somewhat less liable to corrode than the other cast, as was predicted.

Application of Results

Having established the behaviour of an alloy in a solution which would normally cause corrosion, it is possible to decide whether protection is feasible, and also how it can be applied.

In certain borderline cases it is unnecessary to pass an actual anodic current, since it is possible to retain the high potential necessary for passivity by the judicious addition of traces of suitable oxidising agents (or removal of reducing agents such as SO_2). For instance, it is well known that suitable additions of copper, mercury, and other heavy metal ions, all of which can be regarded as oxidising agents for the present purpose, can prevent the corrosion of stainless steel in sulphuric acid. Other more conventional oxidising agents are naturally also possible inhibitors, while the activating effect of SO_2 is seen in Table I. In practice it is often undesirable to add inhibiting impurities, and then the only available alternative is anodic protection.

The successful application in practice of anodic protection on a plant will probably depend on three main factors :—

(1) There must be a reasonable range of potentials over which corrosion is very low.
(2) The design of the plant must be such that the current can reach all places where protection is necessary.
(3) The solution must be reasonably stable at the potential at which it is necessary to maintain the alloy.

Demonstration of Method on Pilot Plant Scale

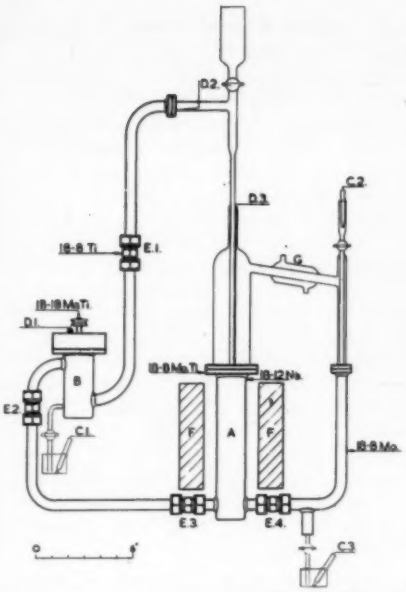
If the above conditions are fulfilled, the current requirements should be small, and should be easily met by simple equipment.

The simplest way of finding out the practicability of the method was to build a small pilot plant. Fig. 2 shows, diagrammatically, a plant built from various grades of stainless steel. There is a central vessel in which the acid can be boiled, and on the left-hand side there is a system of tubes and a pump through which the hot acid is circulated and returned to the main vessel. On the right-hand side there is a condenser, and again a return to the main vessel. Slight modifications to this plant have been made from time to time, but these are unimportant.

For anodic protection, it is essential to have a good electrolytic path for the current, and the method naturally fails to operate on metal merely exposed to "splash" from, for example, a boiling solution. In the present case the pilot plant was built to operate under the most difficult acid conditions, and for this reason

TABLE I.—THE CORROSION RATE OF TWO CASTS OF MOLYBDENUM-CONTAINING 18:8 STAINLESS STEEL IN TWO GRADES OF SULPHURIC ACID.

Sample	Analysis						Corrosion Rate (g./sq. cm./day) in :—					
							Batch A Acid (traces of SO_2 present) of Strength				Batch B Acid (AnalaR) of Strength	
	C %	Si %	Mn %	Cr %	Ni %	Mo %	20%	10%	5%	2·5%	20%	10%
Cast 08980	0·06	0·26	0·41	18·36	8·25	2·70	0·0025 0·0007	0·0000 0·0000	0·0000	0·0000	0·0000 0·0000	0·0000
Cast 02988	0·05	0·29	0·73	17·76	8·35	2·85	0·0028 0·0023	0·0015 0·0014	0·0001	0·0000	0·0003 0·0004	0·0001



A—Boiler. B—Pump. C—Calomel Electrodes.
D—Platinum Electrodes. E—Ermeto Couplings.
F—Furnace. G—Condenser.

Fig. 2.—Diagram of pilot plant used to demonstrate anodic protection. Steel portions—heavy lines, glass—thin lines.

it was made out of glass at those parts which are above the water line. In many cases, however, it should be possible to avoid the use of glass, and an example of this is the shaft of the pump which is not always wetted to the same level, and at which rubbing is an obvious complicating factor. At this place it has been found convenient but not absolutely necessary to gold-plate the danger spots, and it is felt that a good supply of oxygen and a somewhat lower temperature of the acid make protection easier here than might have been expected.

When the plant was first assembled, it was tried out with various dilute acids, but after a few hours' experience, 50% sulphuric acid was added and brought to the boil. At first about 28 mA were necessary to prevent corrosion, but when the last traces of scale and metal fragments were dissolved, it was found that 2–5 mA were sufficient for full protection. Although there were three cathodes, only one was necessary. The cathodes were made of platinum, but other experiments indicate that copper (which is cathodically protected by the current anodically protecting the plant) would do equally well.

The plant had three calomel electrodes also, but again only one was necessary for control. The additional electrodes were useful in monitoring each part of the plant, and in some runs two or three potentiostats were used independently, or in parallel, using these extra electrodes.

In general, the potential at which the plant was controlled was about +0·6 volts (saturated calomel), but other values were tried successfully. On two occasions control was lost owing to electrical faults, and the plant started corroding rapidly, but since potentials were continuously recorded, there was sufficient warning

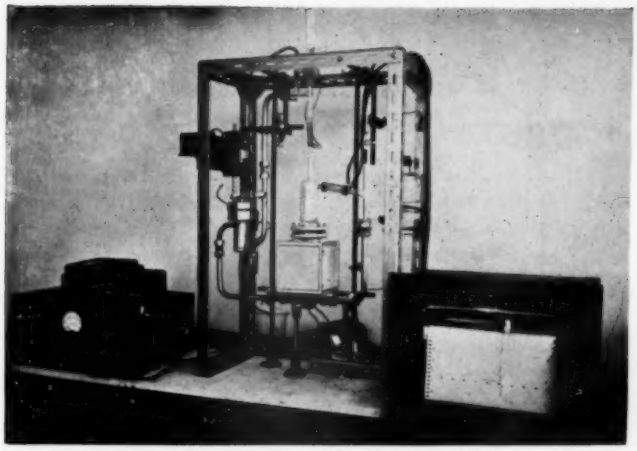


Fig. 3.—General view of pilot plant.

to allow rapid flushing of the plant with water, and no undue damage was done.

The plant has now operated in short runs over a total period of some 200 hours with concentrated acid, and in spite of the fact that during much of this time conditions were deliberately chosen which were not ideal, the plant is still in very good shape and could, on the present showing, operate more or less indefinitely.

Probable Future of Method

Although it is reasonably certain, from the present work, that anodic protection could be applied in practice, it is not yet clear whether there is much call for such a method. The method is perhaps too complicated and, at present, insufficiently well tried to use on expensive plant, but if it does find a simple application, it might eventually "look" less complicated.

There will naturally be a great deal of development work to be done and suitable valves, pumps and other such parts will have to be designed. These difficulties, it is felt, could be overcome, provided there were sufficient call for the method.

At present most of the work has been done on stainless steels, which have a particularly wide range of potentials over which protection is possible, but there is no reason to think that other alloys would not have a sufficiently wide range to be worth investigating.

Acknowledgment

The author wishes to thank Dr. C. Sykes, F.R.S., for permission to publish this paper.

Appendix

The rate of an electrochemical reaction can be converted into an equivalent current density, but the current supplied by the potentiostat does not account for all the corrosion occurring on a specimen. Generally, a cathodic reaction, such as the reduction of oxygen or the evolution of hydrogen, also occurs, and the potentiostat only supplies the current equivalent to the difference between the anodic and cathodic reactions at that particular potential. The loop in Fig. 1, therefore, corresponds to the shaded area of Fig. 4.

Up to a point, with steels of approximately similar composition, the cathodic curve is not thought to vary

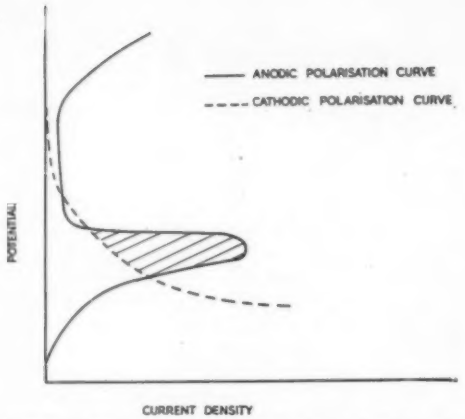


Fig. 4.—Idealised case showing anodic and cathodic polarisation curves for a stainless steel in sulphuric acid.

greatly, and for this reason, for comparative purposes, it is sufficient to measure currents. However, both the anodic and cathodic curves are time-dependent, and a sufficient time must be allowed at each potential to ensure that a steady state is approached, if not reached.

There are two points of theoretical interest shown in Fig. 4. At potentials slightly above the shaded area, one might expect that the potentiostat would supply a negative current, and that is, in fact, found when, as in the case being illustrated, there are three intersects. The points of intersection are important because these are the only potentials which unpolarised specimens can normally take[1]. Only two of these are stable ; the one at high potential is the normal passive potential, while the one at low potential is the normal active potential. The variations with time one normally finds on unpolarised specimens are due to slight changes in the relative positions of the anodic and cathodic polarisation curves. The intersect at intermediate potentials is unstable, because at this place both curves have a negative slope and, therefore, any slight fall below it is not automatically corrected.

That is actually found to be the case, and when the passivity is broken down by, for instance, de-aeration of the solution[2] there is a slow drop in potential to a certain value, after which there is a rapid drop to the active potential. It has been found that within the limits of experimental error, this sudden drop, which sometimes takes less than one minute, occurs over the range of potentials expected.

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All Done by Springs

THE heat treatment of such tools as twist drills usually involves the use of many different types of holders for suspending the work in the salt-bath furnaces. This problem had received considerable attention in the heat treatment department of Firth-Brown Tools, Ltd., specialists in the production of high-speed steel drills and engineers' small tools. The heat treatment in general consists of pre-heating to approximately 850° C., followed by treatment at approximately 1,300° C. Many different types of holder were tried but none of them gave the ease and speed of handling which the works engineers thought should be achieved.

As so often happens, the solution to the problem is a very simple idea—the use of springs to suspend the work from the holder. The drills or, in fact, any tools with tapered shanks, are simply inserted into the springs with a slight twist. The expansion of the end coils results in sufficient tension on the spring to grip firmly. Assembled on a holder, the tools are lowered first into the pre-heating salt bath where the temperature is raised to about 850° C. They are then transferred to the high temperature carboneutral salt bath which is run at about 1,300° C., and are held for the required soaking period. Removal of the tools from the holders is as simple as their assembly, permitting even more saving in labour costs and increasing productivity.

The first material tried for the springs was a normal grade of spring steel. This, however, failed prematurely due to softening by heat flow, since the estimated temperature which the springs must withstand is around 500° C. Springs made of Nimonic 90 were then tried and immediately proved successful. Not only does this material provide the required strength at these temperatures but it is also highly resistant to oxidation and scaling, making it eminently suitable for the continued cycle of heating and cooling. Life of the springs is so far undetermined for, although some have been in daily use for nearly a year, the original springs are still as good as new and would appear to be good for several years' service.

The Plastic Deformation of Metals

Mechanical Engineering Research Laboratory Progress

Although the Mechanical Engineering Research Laboratory building programme is not yet completed, investigations are in progress at East Kilbride and Thorntonhall. The present article surveys the activities of the Plasticity Division, which is concerned with the mechanics of formation and machine shaping of materials.

IN recommending the establishment of an organisation to undertake research in mechanical engineering, the Guy Committee defined this field as falling into seven main divisions, one of which covers the mechanics of formation and machine shaping of materials. Effect was given to the committee's recommendations by the formation of the Mechanical Engineering Research Laboratory and a 70-acre site was secured at the new town of East Kilbride, near Glasgow, where a research station expected to cost over two million pounds is being established. Since the building programme could not be completed for several years, temporary accommodation was acquired at Thorntonhall a few miles from East Kilbride. The division concerned with the mechanics of formation and machine shaping of materials —now known for greater convenience as the Plasticity Division—at present occupies part of the new Properties of Materials Laboratory at East Kilbride, together with various temporary buildings at Thorntonhall.

Plasticity has a well defined meaning; a material which is deformed plastically is deformed permanently. The Division is concerned with every aspect of plastic deformation involved in commercial processes such as rolling, wire drawing, deep drawing, spinning, extrusion, forging and blanking. On the cutting side it is interested in turning, drilling, grinding, lapping and all similar operations. Since virtually every article produced in metal goes through one or more of these processes, it is most important that the fundamental mechanism of plastic deformation should be clearly understood. Though man has been shaping or forming materials for many centuries, and has acquired a wealth of technical "know how," it is only in recent years that there has been any systematic research into the manner in which materials behave under various conditions. If the development of formation processes could be placed on a sound scientific basis, progress would be more rapid and economical.

When the Plasticity Division came into being, towards the end of 1948, neither laboratories nor staff with previous experience in this field were available. Despite these difficulties, good progress has been made in building up the Division, which now has a staff of 27 under Mr. H. Ll. D. Pugh, who is responsible to the Director of Mechanical Engineering Research, Dr. D. G. Sopwith.

The research programme of this Division has been divided into four separate but closely related sections. The Crystal Plasticity Group is studying the properties of crystalline materials on the micro scale, in order to obtain an understanding of the fundamental processes of the plastic deformation of metals. The Plastic Properties of Materials Group is concerned with the macroscopic properties of materials, its aim being to obtain basic knowledge and an understanding of plastic behaviour under a variety of circumstances. The Mechanics of Formation Group is studying the laws governing the plastic deformation of materials in commercial formation processes. Finally, the Mechanics of Shaping Group is concerned with the laws governing the cutting of materials in machine shaping processes.

The Role of Dislocations in Plasticity

Much valuable information on the mechanical properties of materials in bulk can be obtained by studying the movements of dislocations in crystals, and the relation of such movements to the nature and magnitude of the combined stresses. In fact, the movement of dislocations is probably the basic mechanism of plastic deformation.

The physicist's approach to problems of metal behaviour originated in the early 1920's, when enormous discrepancies were observed between the theoretical strength and the actual mechanical strength of even the simplest crystals. About 1930, attempts to explain these discrepancies were made simultaneously by Sir Geoffrey Taylor, Professor Polanyi, and Professor Orowan. These workers all suggested that, even in crystals with a very precise and repeated pattern, slight deviations from perfect regularity might occur here and there, and that even a few of these deviations could have a very considerable effect on the mechanical properties of the material. Deviations forming a regular pattern were termed dislocations to distinguish them from random deviations.

These suggestions were followed up, and eventually the concept of a dislocation became the basis of a very large structure of theoretical work. Until some five years ago, however, this theory was unsupported by direct experimental evidence, and engineers were by no means convinced that it should be taken seriously. Confirmation was forthcoming, however, when workers in a parallel field discovered that the growth of crystals was frequently centred in dislocations.

Further research has shown that it is, in fact, possible to observe dislocations directly, and so determine the actual atomic movements during the deformation of crystals. By studying the nature and movement of individual crystals, the Crystal Plasticity Group at East Kilbride is hoping to verify existing theories and obtain material for future theoretical work.

Most of the major problems presented by dislocation theory cannot be solved without very complex mathematical calculations. In particular, the dynamic behaviour of dislocations has so far defied solution. What happens to a metal when one hits it, pulls it, or applies a stress to it in any other normal way? It is possible that the answers to these questions may be indicated by the experiments now in progress.

Behaviour of Materials under Combined Stresses

When a metal is subjected to a gradually increasing stress, it behaves elastically until a point is reached at which it will no longer return to its original shape on unloading. The yield point or elastic limit can readily be found when the material is subjected to a single stress, but it is desirable that there should be some reliable means of determining this value when combined stresses are applied. While a material remains elastic, stress and strain are related by Hooke's Law, but the behaviour of materials beyond the yield point is quite different.

Research in Britain and elsewhere has led to general agreement that the yield point is approximately in accordance with either the Tresca (maximum shear-stress) or von Mises (maximum shear-strain energy) yield criterion. It is also agreed that the stress-strain behaviour in the plastic state is such that the increments of strain are related to the current stress state. This is different from elastic behaviour, where total strain is related to the current stress. Both the yield criterion and the stress-strain relations are so fundamental to the theory of plasticity that a number of attempts have been made to place them on a firm theoretical basis.

The properties of materials in the plastic region are being studied at East Kilbride both theoretically and experimentally. The theoretical approach is concerned with attempts to predict the behaviour of polycrystalline metals from the known behaviour of single crystals. Commercial metals are aggregates of small crystals, the term " crystals " being used in the sense of ordered arrays of atoms, and to account for macroscopic properties it is necessary to study the behaviour of individual crystals. This research, conducted in collaboration with Professor Hill of Nottingham University, has resulted in a theory of the mechanics of single crystals and of polycrystalline aggregates. A yield criterion for an aggregate of face-centred cubic crystals has been computed on the basis of this theory, which lies between the criteria suggested by Tresca and von Mises. Among metals with face-centred cubic structures are aluminium, copper and nickel.

Further work in this field has led to a theory of deformation textures, which might be defined as the ordering of individual crystallites into special directions under straining. If a bar of isotropic material is examined, it will be found that the individual grains are randomly orientated, but if the bar is strained certain directions of the crystal axes will tend to occur more frequently than others. These are termed " preferred orientations " and vary with the type of straining. This behaviour is exemplified by the phenomenon known as " earing," which takes place when a circular blank cut from rolled material is drawn into a cup.

Work at this level has also enabled stress-strain relations to be predicted, these being of the same form as relations previously suggested from mathematical considerations.

The experimental approach has been designed to throw further light on these problems ; in particular, to determine properties such as yield criteria, stress-strain relations and work hardening, which must be used to describe the macroscopic behaviour of materials, and to determine the validity of the predictions of the theoretical approach. In this work thin cylindrical tubes are subjected to axial tension, torque and internal pressure in a specially designed machine. These experiments will enable the investigators to determine the criterion of yield and the stress-strain relations, and also to show how the yield criterion changes with pre-stress.

The Effect of Hydrostatic Pressure on the Properties of Materials

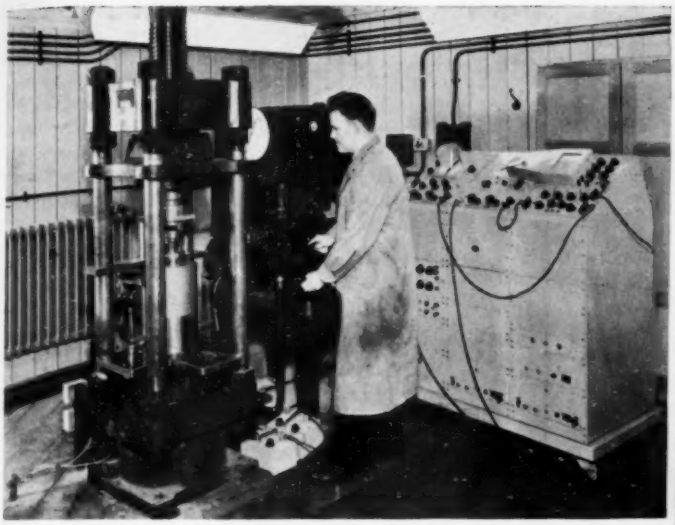
An investigation into the effect of hydrostatic pressure on the plastic properties of materials is likely to yield valuable information on the behaviour of materials in formation and shaping processes. The behaviour of materials under high pressures is quite different from their low-pressure behaviour. Bismuth, for example, is very brittle under normal conditions, but when immersed in a fluid under high pressure it becomes quite ductile, and will withstand considerable strain before fracture. Perspex cannot be reduced in cross-sectional area under atmospheric pressure, but under high pressure considerable necking occurs in tension.

Detailed consideration was given to the design of a suitable apparatus for carrying out simple tests, such as compression, tension and torsion, in a fluid at a constant hydrostatic pressure of up to 150 tons/sq. in. (20,000 atmospheres). Due to the high pressures involved, the investigation is fraught with difficulties. A hydraulic press of the four-column type, having a main ram for loads up to 450 tons and a small ram for loads up to 30 tons, is used to apply loads to pressure-sealed plungers. The high-pressure chamber consists essentially of an outer supporting collar with a slightly tapered bore, inside which is a tapered cylinder with an axial hole of about $1\frac{1}{2}$ in. diameter to contain the high-pressure fluid. The apparatus is so designed that as the pressure-sealed plunger is advanced into the container by the main ram, the central cylinder of the high-pressure chamber is pressed into the supporting collar, so that the supporting pressure increases as the internal pressure increases. The plunger is made of solid tungsten carbide, which is claimed to have a compressive strength of about 200 tons/sq. in.

Measurements of such quantities as pressure, stress and strain are made inside the high-pressure chamber by remote control. Electrical leads had, therefore, to be taken out of the high-pressure chamber and had to be suitably insulated. Precautions had also to be taken to prevent any possible leakage of fluid. The electrical terminals are made of hard steel and are lapped into ceramic insulators, which in turn are lapped into a plug in the actual cylinder. Difficulties were also presented by the measurement of the pressures, which are probably the highest yet achieved in this type of work. They were overcome by the development of a special gauge, which has been calibrated against a special deadweight tester, and is far more accurate than normally available instruments.

Rate-of-Strain Effects

Materials do not behave under very rapidly applied loads in the same way as they do when loads of a similar order are applied slowly. This difference in behaviour has practical significance in certain commercial processes such as drop forging, in which the rates of strain are quite high, and where forces concerned with inertia effects, for example, become important. Apparatus now being assembled will be used to explore strain-rate effects, commencing with quasi-static application of load. It is essentially a screw straining mechanism in which



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Extrusion research equipment.

specimens can be pulled at varying speeds, the strains being suitably recorded. A cam plastometer will also be used to impart very rapid strains to material under investigation.

Little is yet known about the precise effects of strain rates, but work on this subject to date shows that special attention has been given to particular aspects, notably wave propagation in metals under shock loads, i.e. at very high rates of strain.

Mechanics of Extrusion

Plastic deformation of metals in extrusion and forging is being investigated at Thorntonhall. In order to avoid the additional complication presented by temperature, all the initial work on extrusion and forging is being done cold. The object of the study is to determine how materials deform when forced through a die orifice in the extrusion process. This work was started by Professor H. W. Swift at Sheffield University, under an extramural contract, and has now been taken over by the Plasticity Division, M.E.R.L.

All extrusion products may be classified into three types :—

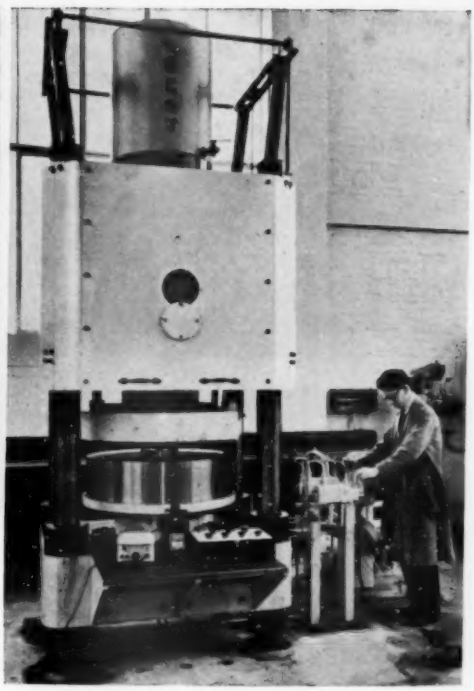
(1) Rod ; a process in which the material has undergone a straightforward reduction in cross-sectional area and, usually, a change in section.

(2) Hooker tube ; a process in which a pierced slug is employed, the metal being extruded between a pilot on a mandrel and the die.

(3) Tubular container ; a process in which the material is constrained to move between the punch head and the die aperture. The container may be rigid or collapsible.

Material can be extruded either by the direct method, in which it is forced out in the direction of the stroke, or by the inverted method in which the piston is hollow and the die is, in effect, forced into the material, causing the latter to flow up through the hollow piston.

By commercial standards the efficiency of an extrusion process may be gauged by such criteria as surface finish, dimensional accuracy, or cheapness. For experimental



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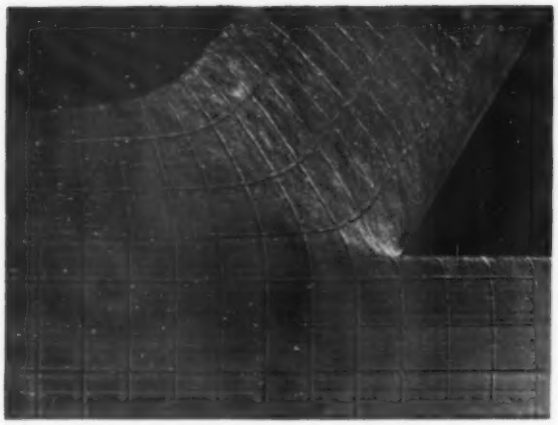
Deforming materials under high hydrostatic pressure.

purposes, however, the extrusion pressure has been adopted as a standard because it is something which can be measured and is reproducible. Continuous records are kept of the variation of extrusion pressure with the displacement of the material inside the die chamber. In this way a characteristic extrusion pressure-displacement curve is obtained for each type of product.

The experimental equipment is quite straightforward. The specimens are slugs of 1 in. or 2 in. diameter, which are dropped into an extrusion chamber of tool steel surrounded by a steel chamber of high tensile strength. The load applied to the punch is measured by means of a load cell of the variable capacity type, the displacement of material inside the chamber being measured by a stroke gauge, also of the variable capacity type. The signals are fed to a two-channel cathode ray oscilloscope and camera equipment. Load is recorded on one tube, displacement on the other, and the time scale is indicated by a third time marker tube. So far as is known, continuous measurements of the load taking place throughout the extrusion process had not been made prior to this investigation, so that no accurate information has been available as to the load required to extrude material into any particular shape.

The next step is to determine the effect on the characteristic curves of such process variables as slug thickness, speed of extrusion, overall reduction in cross-sectional area, tool profile and lubrication. By this means the effect of a particular lubricant, shape of die, or any other variable, can be studied quantitatively.

The deformation of material involves the expenditure of a considerable amount of energy, which appears as heat. This facilitates extrusion because it is easier to extrude a



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A grid inscribed on lead deformed in the cutting process by a tool with a rake angle of + 30°.

hot material. Manufacturers are, therefore, interested in the temperatures developed, and these are also being investigated by the Plasticity Division. A technique has been evolved in which the temperature attained at different points within the metal can be determined throughout the extrusion process. These experiments have so far been confined to lead, aluminium and copper, but the work will be extended to cover other metals. So far only a few conclusions—in particular, those relating to the effect of extrusion ratio and to the effect of lubricant—can be put forward regarding the process as a whole. There are minor differences in the behaviour of the individual metals, when tested under similar conditions, which cannot readily be explained at this stage.

The Group is also interested in the flow of metals during the deformation process, which is being studied by splitting the specimens and inscribing grids on them. The split specimens are then extruded in the usual manner, and by examining the deformed patterns much information can be obtained as to the behaviour of the material in the extrusion chamber under certain conditions. Lead, aluminium and copper, for example, all show a tendency to pipe during the latter part of the extrusion process. This tendency is reduced when the die has a radiused or conical entry.

Forging

In the study of deformation during forging, an attempt is being made to find out how far industrial practice can be accurately represented by small-scale experiments. Model tests are particularly attractive because modifications or changes in the set-up—which are the essence of research—can be done much more easily on a model scale.

Tests are being conducted on model drop hammers of different sizes, by which appropriately scaled specimens of suitable shapes and dimensions are deformed. From a study of the results obtained, it is possible to ascertain the conditions necessary to ensure that the same relative deformation occurs on small and full-scale specimens: some interesting information has already been obtained. For instance, it has been shown that the rate of strain effects differ with the scale of the model, so that in order to carry out model tests on the forging process the investigators must know how to interpret these effects qualitatively.

Experiments are also being carried out to find the relevant factors in the deformation of metal between parallel plates, in a drop hammer, in half-open dies (which constrain flow in one direction) and closed dies (when the material is constrained in all directions). As in the case of extrusion, instrumentation techniques have been evolved to measure loads and displacements during the duration of the impact blow on a specimen.

Mechanics of Cutting

The Mechanics of Cutting Group is also located at Thorntonhall, where it is studying the deformation of material when cut by a tool. This presents difficult problems, even when the investigation is confined to such a simple process as orthogonal cutting, which occurs when the undeformed chip thickness is constant and the cutting edge is perpendicular to the cutting direction.

In recent years certain theories have been put forward to explain what happens when a material is cut by a wedge-shaped tool. Ernst and Merchant have related certain quantities, namely the angle of the shear plane, the angle of friction set up at the tool interface, and the rake angle. The results obtained from orthogonal cutting tests on mild steel, copper and tellurium-lead carried out at M.E.R.L. did not confirm the relationship suggested. A theoretical analysis of this particular problem is being made, and in order to provide basic information for this work a series of experiments is being undertaken.

A tool is set up in a shaping machine and an orthogonal cut is made on a suitably prepared specimen. The deformation set up in the work material and in the chip is determined by means of grids. The horizontal and vertical forces required to cut the material are measured by a dynamometer mounted in the head of the shaping machine. From these measurements, the angle of friction at the chip-tool interface can be determined. The variation of the friction angle with the rake angle is investigated. It is also possible to record the cutting process on a ciné film, or a photograph can be taken of the tool, chip and work material at any desired point of the cut. The results of this investigation are encouraging.

Wear of Tools

One of the most important properties of a cutting tool is its resistance to wear. Under normal cutting conditions, tool wear experiments usually involve a large expenditure of work material and take a long time. A micro technique has therefore been developed, which involves preparing the tools in such a way that minute amounts of wear can be detected. The clearance and flank faces are polished to metallurgical standards and the geometry of the tool surface is accurately checked by interferometric methods. The final polish is given by diamond dust, and when the surface is observed through a microscope with a suitable magnification, some of the score lines produced by the diamond powder can be seen. Using one of these lines as the datum, the distance to the tip of the cutting tool is measured. The tool is then set up and a small cut is taken over a short interval, which might be a matter of seconds. On examining the tool under the microscope, it can be seen that a wear band has formed on the flank face, showing how the material has been abraded under the cutting action. By measuring the increasing width of the wear band as more and more material is cut, a curve is

obtained of flank wear against cutting time or distance cut. Wear takes place quite rapidly in the early stages when the sharp edge crumbles, after which the curve flattens out and becomes linear.

The linear portion of the curve so obtained is adopted as a criterion and termed the flank wear rate. The effect of any work material on the wear of a cutting tool may then be found by setting up a small billet and taking appropriate cuts. In some materials it is found that tool wear rate increases as the centre of the billet is approached, whilst in others the opposite effect was observed. No single factor capable of accounting for this variation could be detected by metallurgical examination. These results were eventually traced to the effects of the distribution of manganese segregates in one case and of silica stringers in another, the preferential distribution of these impurities being sufficient to give the type of tool wear obtained. For these experiments a perfectly homogeneous material giving a constant tool wear rate across its section is most desirable. The validity of the results is being checked by full-scale wear tests.

The flank face wear was selected for the initial work because it is the first to appear, but the investigation is being extended to ascertain the effect of size of cut, and of tool angles, on the rate of tool wear, and to determine the nature of the wear mechanism also on the clearance face and in the " crater " area of the tool. It is hoped to establish the conditions which cause the proportions of flank and crater to vary from one combination of work and tool material to another.

Temperature Distribution in the Cutting Process

In most aspects of the cutting of metals, the temperatures developed are of importance. Making use of the mode of deformation of a material in orthogonal cutting, they have been determined theoretically using the " relaxation " technique, which might be described as a process of successive approximation. The accuracy of the results cannot readily be checked experimentally because it is difficult to measure a temperature at a point. The available evidence suggests, however, that the figures obtained are approximately correct. It has been shown experimentally, by cutting steel with tungsten carbide tools, that when the temperature approaches 1,300° C. the tungsten is removed by chemical action between the steel and the tungsten carbide. Calculations indicate that temperatures of this order are produced on the cutting face, where wear actually occurs.

Unusual Use of Duralumin

Britain's Largest Sand Yacht

BRITAIN'S largest sand yacht, which is to attempt to establish the first British native speed record over the flying mile, at Lytham St. Annes this month has been constructed mainly in light alloys, including Duralumin supplied by James Booth & Co., Ltd., to meet the requirements of strength and lightness.

The yacht, known as the Coronation Year Mark II, was designed and built as a hobby by Mr. R. Millett Denning, a Hampstead man who became interested in the sport of sand yachting about 10 years ago. He designed the first yacht (Coronation Year Mark I) ever to be built of light alloys last year—it weighed 7 cwt. (unladen) with a sail area of 246 sq. ft. and reached a speed of 50 m.p.h. The Mark II was developed from this. It has a sail area of 286 sq. ft., is 30 ft. high, 26 ft. long and 16 ft. wide, and weighs 9 cwt. unladen. It is expected to reach speeds of more than 75 m.p.h. and, while doing so, be able to turn in its own length.

For the record attempt there will be a two-man crew—the mainsail operator and the tiller man—but subsequent developments will probably require a four-man crew as the installation of a port and starboard Genoa jib is under consideration. The unique arrangement at the masthead is designed to eliminate any undue stress in the Duralumin gaff boom when the cotton mainsail is filled during racing. The entire yacht is assembled by a system of wing nuts and couplings and can be dismantled and transported on a Land Rover with ease.

It is interesting to note that the first known sand yachts in this country appeared at Southport in 1895; they were mainly of timber construction and fell into disuse owing to the advent of the motor car. There has been a revival of interest in the sport of latter years in other countries, and Mr. Millett Denning maintains that there are numerous stretches of sand around our own coast which would be more than suitable, particularly as they are not used to any great extent during the winter, spring and late autumn. The Fylde International Sand Yacht Club has now been formed at Lytham St. Annes to popularise the sport over here, and the attempt on the speed record will be held under their rules.

The Austenite-Martensite Transformation

A Survey of Work Carried Out at Birmingham University in the Period 1947-1953

Originating in work on the welding of tank armour steels, a fundamental study of the transformation of austenite to bainite and martensite has been made by a group of research workers at the University of Birmingham in the post-war period. Numerous papers have been published on various aspects of the work, and a summary incorporating the main findings, prepared for the British Welding Research Association by Dr. T. Ko, a leading member of the group, is presented here.

THE following is a brief account of some work carried out at Birmingham University in the period 1947–1953. It forms the natural extension to work commenced as early as 1940, and which was maintained continuously until 1953, though in changing forms, under the direction of the late Professor D. Hanson. In the period 1940–1947, work commenced on the welding of tank armour steels, and this gradually changed in character to a more fundamental study of the austenite–martensite transformation. In 1947, the sponsorship of the work changed hands from the British Welding Research Association to the British Iron and Steel Research Association, though the former body has since continued to support the work.

The work carried out since 1947 has been directed to a study of the following problems :—

(1) The effect of high temperature heating on the structure and mechanical properties of hardened structural steels, particularly those of low weldability.

(2) The stresses in martensitic steels due to transformation which may affect the mechanical properties.

(3) Fundamental studies on the kinetics of martensitic and bainitic transformations in steel.

The Effects of High Temperature Heating

The basic reason for making such a study was given in a report presented to the Symposium on Metallurgy of Steel Welding organised by the British Welding Research Association, in which Wheeler and Kondic described some preliminary results concerning the effect of heating to high austenitising temperature on the tensile properties of a fully hardened En 26 steel. In an extended investigation covering seven steels to specifications En 25 and En 26, it was found that the following changes were observed in the structure after heating to high temperatures.

(i) Overheating and burning of the steel, associated with embrittlement.

(ii) Fracturing by cleavage along cubic planes of austenite in one steel with a low Mn/S ratio after heating to above 1,350° C.

(iii) In most of the steels, a tendency for the formation of the more ductile intermediate transformation products after heating to very high temperatures.

While the steels behaved differently in detail, the general trend was the same. Ko and Hanson showed that the embrittlement after high temperature austenitising was due to (a) grain growth of austenite, and (*b*) overheating and burning. In view of the importance of these phenomena, they made an investigation into their causes, which had attracted much attention since the first World War and particularly during the second World War, as can be seen from the large number of contributions to a discussion held at the Iron and Steel Institute in 1945. By using a new technique, and examining the actual grain interface instead of the polished surfaces, they showed that overheating of steel occurred when numerous very fine precipitated particles of manganese sulphide were observed on the austenite grain interface, and that a steel became " burnt " when a eutectic structure was observed at the grain boundaries after cooling to room temperature. These precipitated particles were too thin to be visible in a polished section. Ko and Hanson also confirmed that these phenomena were independent of the atmosphere and occurred during heat-treatment in vacuo. They suggested that the solubility of manganese sulphide increased with increasing temperature, and that some sulphide was taken into solution during heating to above 1,250° C., and reprecipitated, on cooling at a suitable rate, along the grain boundaries of large curvature. These precipitated particles lowered the strength along the planes of precipitation, and when the martensitic matrix was properly toughened, the steel would fracture along these planes, giving rise to the familiar faceted fractures associated with an overheated steel. The solidus of a steel was lowered by the presence of sulphur in solution, and a high-sulphur, high-phosphorus liquid was formed at the grain boundaries at a temperature below the solidus of an iron-carbon alloy of equivalent carbon content. On cooling, the liquid solidified as a eutectic of iron and (Mn, Fe) S. The phosphorus was deposited with the iron, giving rise to a light-etching network (with nital) along the austenitic grain boundaries, a structure usually observed in " burnt " steels. These views were substantiated by designed experiments using pure materials, and by experiments made by others, and are now generally accepted.

The fracturing by cleavage in certain steels was found to be due to a cause similar to that of overheating. Under certain conditions the sulphide precipitated on the cubic planes of austenite in addition to that at the grain boundaries, weakened the steel after hardening, and facilitated the propagation of cracks along these surfaces.

The slight recovery in the ductility and the drop in tensile strength of the air-hardened steels when they were austenitised in a certain range of temperatures were found to be caused by the formation of bainite at higher temperatures, before the martensitic transformation

set in. The effects on the mechanical properties, and the amounts of upper and lower bainite after the same treatment, were not the same in two steels of nearly identical composition made by different processes. These effects were correlated with the observation that the bainite formation was accelerated by high temperature austenitisation. Further investigations on the effects of high austenitising temperatures on the bainite transformation of various steels showed that this acceleration was limited to Ni-Cr-Mo steels and was not found in others. The accelerating effect in Ni-Cr-Mo steels could be completely removed by re-austenitisation, but annealing at a lower temperature in the austenitic range after high temperature heating, without interposed transformation, only removed part of the effect.

Stresses in Martensitic Steels

It has been suggested that the internal stresses set up during martensitic transformation may affect the tensile properties of hardened steels when the ductility is low. This receives certain support from the well known observation that high-carbon martensite in a quenched steel tends to contain cracks, actual and potential, even when a certain amount of austenite is retained. These stresses may be very high, and it is desirable to have a reasonably reliable value for their magnitude. This can be determined from the extent of line broadening in the X-ray diffraction pattern, because the residual internal strains in martensite produce lattice parameters of different values centring about a more frequently observed average, and the line broadening is a function of the magnitude of the strain or internal stresses, provided that the broadening is not due to small particle size of the martensite. This implies the formation of some form of sub-structure within the original grains, which would have the same effect as stresses.

The line broadening due to stresses and that due to particle size can be differentiated by the constancy of the products of different trigonometric functions of the diffraction angles and the corresponding line breadth. A preliminary study by Wheeler and Jaswon in this respect showed that the line-broadening in X-ray diffraction patterns of martensite was more likely due to the presence of stresses than to particle size, but more accurate results could not be obtained by the normal technique of recording diffraction with photographic films, because of the low accuracies caused by the interference of background diffraction, and the difficulties of maintaining constancy of processing and densitometry of films.

A new technique involving the use of Geiger counters in place of photographic films was developed by Arndt and Smith in collaboration with other members of the staff of the Department. In this method the photographic film was replaced by a Geiger counter placed on a spectrometer base, which provided a method of accurately measuring the diffraction angles. The number of counts given by the counter, which measures the discharging of the counter due to the ionisation effect of the X-ray beam, increases with the X-ray intensity. By measuring the number of counts at different angles, a distribution of the intensity of the diffracted X-ray can be registered. Numerous difficulties were encountered during the development of the technique, but the efforts were rewarding. The importance of the development made under this project has been widely acknowledged, as the results obtained on the Geiger counter spectrometer have contributed not only to a greater understanding of the stress system existing in martensitic steels, but also to knowledge in the very important field of plasticity and work-hardening of metals and alloys.

Using the method developed, Smith studied the line broadening in the diffraction pattern of martensite in hardened nickel steels, and, by carrying out Fourier analysis to obtain the true physical broadening from the observed spectrum, he showed that the line broadening was due mainly to internal stresses, but there was an indication of the presence of sub-structure in the martensite. He concluded that (*a*) the stresses in martensite were of extremely short range, (*b*) the internal stresses increased rapidly with increasing carbon content, and (*c*) the average stresses were about 0·4–0·6 of the tensile strength of the steel. The maximum internal stresses must be much higher, but owing to the rapidly varying magnitude of stresses, there is little meaning in estimating the value of the peak stresses. It is certain, however, that the stresses generated during the formation of martensite are sufficient to cause plastic deformation in austenite and in martensite, although it is not possible at present to enumerate conclusively the sources of the stresses and the nature of the sub-structure in martensite, because of the lack of understanding of the mechanism of martensite formation.

Kinetics of Martensite and Bainite Transformation

The mechanism of martensitic transformation, and particularly the formation of martensite of high carbon steels along irrational habit planes, are little understood. Jaswon and Wheeler attempted to predict the habit planes from an entirely new approach. They proposed that the habit plane, i.e., the plane of austenite in which the martensite plate lies, is the one that undergoes no rotation during the transformation. They showed, by applying a strain tensor method, that the orientation relationship between austenite and martensite determined by Kurdumov and Sachs automatically resulted in the observed habit planes from the above assumption.

Jaswon and Wheeler's results have been shown by later work to require certain modifications, but their concept of applying the mathematical method of strain tensor analysis to the problem of crystallography of transformation has been adopted in all the subsequent important crystallographic studies of martensitic transformation, not only in ferrous alloys, but also in non-ferrous materials. As the martensitic transformation is one of the three fundamental types of phase change, the contribution made by these investigators has been acknowledged by leading crystallographers as of great importance.

The mechanism of the other, least understood, transformation, the formation of bainite, has also been studied. A vast quantity of work has been done in the 20 years since the discovery of intermediate transformation products in the temperature range between pearlite and martensite formation, but the mechanism of their formation was unknown. Ko and Cottrell investigated the transformation by studying the surface distortion associated with the transformation, and concluded that bainite formed by a shear transformation during which the coherent growth of nuclei was very slow. They showed that the surface distortion of a specimen due to

bainite formation was similar to that obtained during martensitic transformation, and was only possible if the interface between austenite and martensite remained coherent, and if the coherence was maintained by translation of atoms of austenite ahead of the moving interface in the direction of shear. But they showed experimentally, by making hot-stage microscopic observations, that, unlike martensite, the bainite formed by slow growth from nuclei. They also concluded that there was no fundamental difference between the bainite formed at different temperatures, although their completely different structures had led to the names of acicular ferrite, upper bainite and lower bainite. The differences between these structures were due only to the position of carbon deposited during the formation of bainite.

Ko and his co-workers have proposed a new theory of bainite transformation—that the coherent growth is controlled by the removal of carbon from bainite, by diffusion of carbon into austenite, by precipitation as carbides, or a combination of both. The reduction in carbon concentration reduces the strain due to density change, and increases the free energy of transformation, thus providing a larger driving force for a shear transformation which cannot proceed as rapidly as martensite transformation. The exact method of removing carbon depends on the temperature of transformation: at high temperatures, diffusion of carbon in austenite is rapid, and bainite free from carbon is obtained. As the temperature is lowered, the slow diffusion of carbon in martensite leads to its precipitation as carbide in the vicinity of parallel carbon-free bainite plates, resulting in feathery or upper bainite. At lower temperatures the carbon will be precipitated as carbide within the bainite, giving rise to the formation of lower bainite. The suggestion that carbon diffuses out of bainite into austenite has received support from further work, which showed that the α-iron precipitated by the bainite mechanism (acicular ferrite) was free from carbon, and also from investigations made by Wever and his co-workers in Germany, who showed that the carbon concentration in austenite increased during the formation of bainite, and that an austenite sheath enriched in carbon was observed around the bainite plates. The role played by the precipitation of carbide in promoting the coherent growth has also been demonstrated by Ko, who showed that, choosing the right conditions, it was possible to promote the further growth of a martensite plate into martensite and/or bainite by tempering.

Acknowledgments

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Development in Pre-Packaging Technique

ONE of the first " dry rooms " in Great Britain to conform to new Ministry of Supply regulations governing the pre-packaging of radar and electronic equipment for the Services has been built by Geo. Salter & Co., Ltd., the West Bromwich spring manufacturers, at their No. 2 factory in Spring Road, Smethwick.

This marks a significant advance in the technique of pre-packaging—the protection of goods both in transit and for long periods of storage—which the Salter organisation has developed considerably during the past few years. What is now the Salterpak Division of the Company has grown from a small section which initially devoted itself to pre-packaging the firm's own products to Ministry of Supply standards, giving protection against tropical heat, moisture, insects and other hazards. Neighbouring Midlands firms fulfilling contracts needing similar pre-packaging, but without their own resources, asked Salter to undertake this work, and now nearly a hundred men and women are wholly employed by the Salterpak Division, handling an astonishing variety of products from nuts and bolts and hand tools to massive but intricate and delicate electrical equipment.

So far as radar and electronic devices for Service use are concerned, the Ministry has now ruled that in addition to being pre-packed by methods which ensure that they are impervious to outside climatic conditions, each item of equipment must be thoroughly moisture-free before packing begins. This regulation was made after Service experience had indicated that the efficiency of some types of radar equipment had been impaired not by external moisture but by the action of the moisture contained in the air of the room in which they were packed. Obviously some of this air must be packed in with the equipment, and changes in temperature can cause the moisture to leave the air and settle on the equipment, perhaps with disastrous results.

The new Salter " dry room," itself uses an impressive bank of electronic equipment to keep humidity at a fixed low level and to control temperature. Equipment is stored for specified periods and must also be packed inside the room to ensure that it reaches its eventual user unaffected by humidity.

Exports to Persia

WITH the announcement about the accord on points of agreement which has been reached in the negotiations concerning Persian oil, it is expected that there will be fresh opportunities for United Kingdom firms to supply goods and services needed by the Consortium and the National Iranian Oil Company. Exporters requiring specific information about exports to Persia are invited to write or telephone to Commercial Relations and Exports Department, B.O.T., Horse Guards Avenue, London, S.W.1 (Tel.: TRAfalgar 8855) and, where appropriate, to Export Licensing Branch, B.O.T., Atlantic House, Holborn Viaduct, London, E.C.1 (Tel.: CITy 5733).

Micro-Indentation Hardness

Its Elastic, Plastic and Fracture Components

By P. Grodzinski, A.M.I.Mech.E.

"The mere fact that there exists no satisfactory definition of what is to be understood by 'hardness' is an indication of the difficulties of the subject. The generally accepted definition is that hardness is a measure of the resistance which a crystal exerts, according to area and direction, against damage to its surface, which is a poor description of the various types of hardness test, and which provides no physical basis for a study of the subject."—H. Tertsch, "Bemerkungen zum Härte Problem," Radex Rundschau No. 3, 1950.

STATIC indentation hardness is a relatively new conception. Although the method of testing now generally accepted was first announced in 1901 (by Brinell[1]), the idea can be traced further back to about 1880, but before that date the records refer only to scratch methods. The basic concept of indentation hardness is due to Hertz[2], who advanced the idea of suppressing the dynamic factor invariably connected with scratch hardness, namely, speed of movement. In the Hertz conception the material was considered to remain in the elastic condition, whilst the ideas of Brinell and his successors allowed for the load exceeding the elastic limit: the Hertz conception, therefore, had found little application in practical hardness testing. After 1900, hardness testing developed in the following directions: (*a*) the use of indenters of greater modulus of elasticity, in order to exclude the influence of indenter deformation; (*b*) indenter shapes with proportionality between depth and length of indentation; and (*c*) lower loads and smaller indentations. The developments mentioned under (*c*) started in 1937 when Lips[3] introduced the first simple micro-hardness tester.

The conception of micro-hardness testing at very low loads shifted hardness testing from the range of plastic deformation to the elastic-plastic range and even into the elastic range, in which, after the application and removal of a relatively small load, no deformation is visible by ordinary means of observation. With very brittle materials, micro-hardness testing frequently results in fracture, and hardness testing, therefore, covers the whole range of stresses applicable to solid bodies, causing, at low loads, elastic or elastic-plastic deformation, and at high loads, plastic deformation or fracture.

The main aim in macro-hardness testing was to make the hardness value independent of the load, as was classically demonstrated by Smith and Sandland[4] more than 25 years ago, when they introduced the square-based diamond pyramid indenter. This clearly demonstrated that with such a diamond pyramid, at loads up to 30 kg. on ordinary engineering materials, mainly plastic deformation was produced.

Similar observations have been made with the double-cone indenter to show that the conventional macro-hardness in kg./sq. mm. is practically constant, regardless of the load. Workers in the micro-hardness field are, however, aware that in the low-load range hardness expressed in kg./sq. mm. is dependent on load. This has led to a desire to find a bridge between the different ranges.

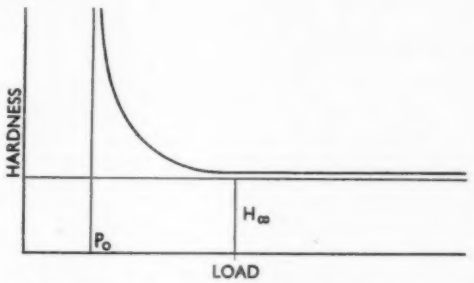


Fig. 1.—Hardness may follow a hyperbolic curve with an asymptote at $P = P_o$ and another at $H = H_\infty$.

In line with the suggestions of Bückle[5] and others, the following load ranges will be distinguished:—

Micro-hardness	..	1–200g. (5–50g.)
Low-load Hardness		200g.–10kg. (200g.–1 or 2 kg.)
Macro-hardness	..	above 10kg.

The values in brackets are the usual or characteristic ranges.

The Study of Plastic Hardness

Micro-hardness and low-load hardness testing are often carried out with a square-based diamond pyramid used in conjunction with a microscope, but this is not an essential combination. As the microscope can only be brought into action when the load is removed, this method is limited to the elastic-plastic and plastic ranges: furthermore the use of a symmetrical or square-based diamond pyramid leads to early fracture, even at small loads, due to the high specific pressure. The elastic behaviour of the material under load can only be deduced by a careful study of the shape of the indentation and its walls, a method frequently applied.

By using the diagonal or the length of the indentation, which does not show much elastic recovery, in the evaluation of micro-hardness measurements, the elastic part of the deformation is considered in part. Furthermore, the indentation area is introduced, not as measured but as unrecovered area, a conception frequently used (Knoop hardness and conventional double-cone hardness). With these assumptions the elastic behaviour is only partly considered, however, the elastic range being much more extensive, as will be shown later.

In conventional micro-hardness and low-load hardness testing, the limit of the plastic range can be observed by the fact that below a certain load, the hardness value H in kg./sq. mm. shows a remarkable increase (Fig. 1).

Fig. 2.—Double cone indentation on glass covered with a thin layer of soot. × 250

One school of thought (Tarasov[6] and Schulze[7]) introduces a constant correction factor c for the elastic behaviour of the material :—

$$H = \frac{P}{k(d+c)^2} \quad (1)$$

instead of $H = \frac{P}{kd^2}$ (2)

The factor c for each individual material is determined in such a way that one obtains a constant hardness H in both micro- and macro-ranges. This cannot be considered as a satisfactory method, as the constancy of the elastic hardness H under different loads, as well as that of the elastic recovery, is rather a presumption.

The increase of hardness with smaller load, and, therefore, smaller length and depth of indentation, is called by Shaw[8] "size effect," and thought similar to effects observed in torsion and cutting tests, when the surface layer and not the underlying material is tested.

Another, and probably more fruitful, approach is to realise that the point where the conventional hardness H begins to increase is a point where accepted relationships begin to lose their value. It is the point where mainly plastic deformation changes into elastic-plastic and ultimately elastic deformation.

If no further influences are present, with still further reduced load the hardness H increases, and should increase to infinity at some particular load P_o (Fig. 1)[9]. Actual measurements have been made in some instances (Table I), but obviously the method of observation used, for example, the microscope, must have a considerable influence on the results, and the electron microscope may yield better information. The hyperbolic increase of the plastic hardness has been reduced to an axiom by Schulze[7], who assumes that with any material, and with a correct diamond indenter, the micro-hardness should increase continuously as the load decreases. This behaviour has not been observed in some cases due to a blunt edge of the indenter and the effects of the surface roughness of the sample ; in others, a fall of the curve at still smaller loads is observed, occasionally, leading to a "maximum hardness." Schulze assumes that inaccuracies in some hardness testers at low loads are responsible for this : whilst there may be something in this contention, it cannot yet be regarded as generally true until further experimental data are available.

Assuming a hyperbolic law with two asymptotes for $P = P_o$ (vertical line) and $H = H_\infty$ (horizontal line), thus Fig. 1

$$(H - H_\infty)\,(P - P_o)^1 = C \quad (3)$$

* A key to the notations used in the article was included as an appendix.

TABLE I—MAXIMUM LOAD P_o FOR WHICH NO INDENTATION IS VISIBLE AT HIGH MAGNIFICATION.

Material	Load (g.)
Synthetic ruby	20
Silicon carbide	25
Boron carbide	25

Double-cone diamond indenter used.

$$\text{or } H = \frac{C}{(P - P_o)^1} + H_\infty \quad (3a)$$

This relation seems to conform with the usual observation that when plotting load P against the plastic deformation d in a log-log diagram, a power law is obtained by the Meyer analysis :

$$P = a\,d^n \quad (4)$$

Combining this with the hardness definition (2), we obtain

$$H = \frac{a^{2/n}}{k} P^{2/n-1} \quad (5)$$

i.e., the hardness value is inversely proportional to a power of the load P so that with decreasing load the plastic hardness increases. Whilst this is in conformity with many experimental observations, it cannot be proclaimed as a general law of hardness, owing to the fact that the elastic component of hardness is not considered.

This discussion has brought to light a point of a "philosophical" nature previously dismissed as nonsensical by certain experimenters[10].

"Is the infinite hardness H at a load P_o not contradictory to experience, since it would indicate that all materials would have the same hardness, i.e., an infinite hardness."

It is quite obvious that the value P_o is different for each material (see Table I) according to its hardness, and, therefore the observation of an infinite plastic hardness is not in itself nonsensical, it only means that there is zero plastic deformation, whilst elastic deformation may still be present but not observed.

Need for a New Definition of Hardness[11]

The experiences recorded above are interesting, but they must be unsatisfactory for those who want to know the hardness of a certain material in relation to other materials. As just shown, the Meyer relation (4) may be used as a relatively satisfactory description of the phenomenon of indentation. As the constant a may be valid for the total range of observations, the conventional hardness H can be rewritten as

$$P = Hkd^n \quad (2a)$$

in which $n = 2$ is given through Kick's law of proportionality, we may regard

$$a = Hk = h \quad (6)$$

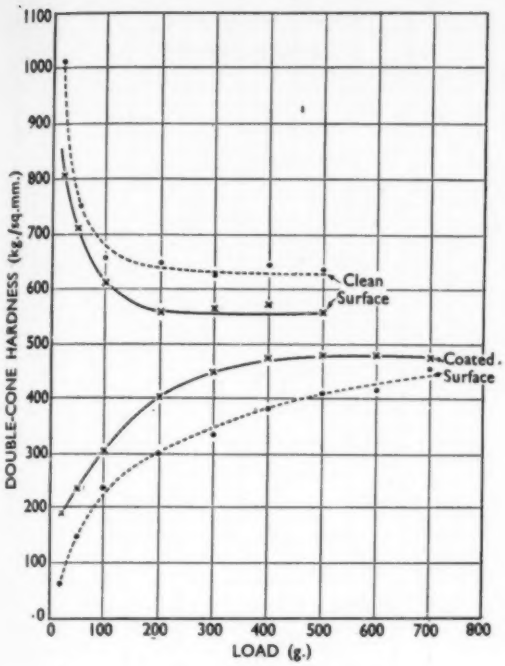
as a new hardness value, which follows the law

$$h = \frac{P}{d^n} \quad (7)$$

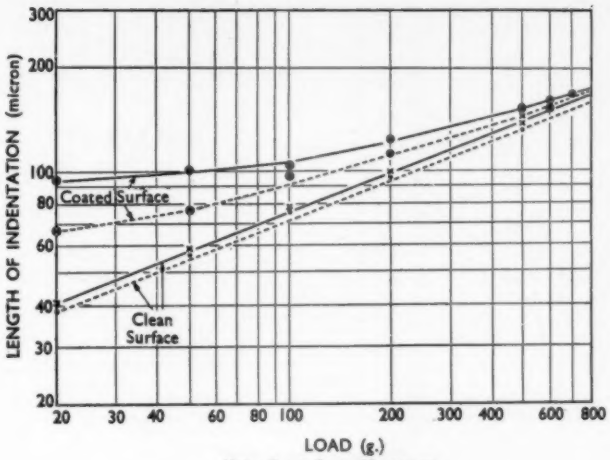
where h is defined as that load which causes a deformation of unit length ($d = 1$).

With this definition, the curve in Fig. 1 is fairly accurately described for all materials from the softest to the hardest, such as sintered carbide or silicon carbide, but excluding diamond. A fair comparison between materials is given as they are all indented for an equal length or equal depth of impression.

Any deviation from the law $P = hd^n$ (7a) will, of course, become obvious as before, with the difference that



(a)—Linear diagram.



(b)—Log-log diagram.

Fig. 3.—Double cone micro-hardness tests at various loads on a razor blade in the normal condition and coated with a thin layer of soot. The continuous lines indicate in (a) tests across the rolling direction and dotted lines tests in the rolling direction. In (b) the order is from top to bottom: in rolling direction; across rolling direction; across rolling direction and in rolling direction. Note that the vertical axis represents hardness in (a) and length of indentation in (b).

the above rule or law is now the basis, whereas formerly no such basis was available. Further, as already mentioned, in micro-hardness testing with low loads the surface texture may be important. The contact area used in conventional hardness calculations loses its sense, whilst the load still determines the size of the indentation. Therefore, the definition given above has the advantage that it does not introduce a condition which is not present, at least at the beginning of the test or at small loads, and which may have led in some instances to the observation of " bent down " hardness curves and the appearance of a " maximum " hardness.

The Observation of Elastic Hardness

Elastic hardness can be observed by comparing the shape of the indenter with that of the indentation after the load has been removed. For instance, with diamond pyramid (Vickers) indentations one can observe, according to the material tested, a deformation of the indentation. Such findings are facilitated by interferometric investigations[12], but hitherto no theory has been advanced to provide quantitative data. The following techniques have been developed in the laboratory of the author for the determination of elastic hardness.

(*a*) *Coating Techniques.*

A thin silver film (0·1 micron) is evaporated on to the surface to be tested[9,13]. When loaded, this film is cut by the sharp indenter edge (double cone) and thus compressed under the edge, it cannot reform itself, so that subsequently it is possible to determine the amount of deformation when the indenter was loaded. The difference between the deformation of the coated surface and the deformation found on a clean surface must be due to elastic influences. The result is slightly impaired by the thickness of the silver layer.

In a variation of this technique, the polished surface is held near a candle flame so that it acquires a thin layer of soot[2]. On making an indentation three areas are to be observed (Fig. 2): (1) the outer undisturbed area; (2) a disturbed area from which the soot coat appears to have been removed; and (3) the actual indented area. The length of the indentation is slightly larger than measured on a clean surface, thus indicating the elastic recovery.

Such tests have been made on plate glass and on razor blade steel, and in the latter case the directional characteristics of the rolled steel could also be determined[14]. This investigation produced certain results which are important in the present discussion. One might assume that the material would be softer in the direction of rolling than across it, but testing on a clean surface showed the hardness in the rolling direction to be greater than that across it. On applying the coating of soot, however, the material was found to be softer in the rolling direction and harder across it, as expected. Furthermore, the hardness of the uncoated material increased with smaller loads below 100 g., and that of the coated material fell almost to zero at small loads. This now contributes to the previous discussion whether hardness at small loads tends to increase or decrease. By lightly treating the surface of the test sample, the two different results can be demonstrated on the same material.

On plotting the test values on a log-log scale, the clean surface is represented by a straight line and the coated surface by a curve (Fig. 3b). The vertical differences between the two lines give the amount of elastic recovery, which is appreciable. The curves for the plastic deformation (clean surface) are practically straight lines and can, therefore, be described by a power law $P = ad^n$, where P is the load in kg., a (the constant) is the ordinate for $d = 1$, d is the length of the indentation, and n is the Meyer coefficient. The total deformation (coated surface) deviates from a straight line below a certain load,

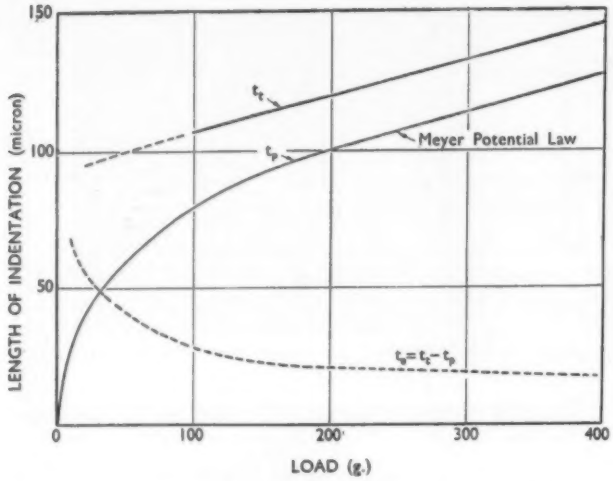


Fig. 4.—The results in Fig. 3b replotted on a linear scale.

for instance, 50 g., when tested across the rolling direction. Since for zero the total deformation should be zero, the test does not seem to describe correctly the conditions at low loads. On the other hand, the measurements of the total deformations are more certain than those with only plastic deformation.

The values for the test across the rolling direction have been re-plotted in a linear diagram (Fig. 4). Above a load of 200 g. the curves for the total and plastic deformations are practically parallel straight lines, i.e. the elastic deformation is constant or independent of the load, but below this load the rate of elastic deformation increases. This, however, is approaching the uncertain field which has been discussed earlier, and the effect may be due to the shape of the curved indenter.

(*b*) *Depth measurement.*

Reference has often been made to the fact that depth measurements of indentations are more reliable than length measurements, the latter being influenced by wall formation and ridging. On the other hand, depth measurements have the disadvantage of being much smaller, and necessitating much more sensitive measuring equipment. In micro-hardness and low-load hardness testing, depth measurement must obviously be made under load, thus excluding the use of the microscope.

In an instrument[11] developed by the author, the load on the indenter (preferably a double cone) is increased from zero, and the depth of indentation can be re-measured when the load is removed, and in this way both the elastic and plastic components of hardness can be determined. This apparatus records, of course, the depth of movement of the indenter from the contact of the surface under no load until the bottom of the indentation is reached, and the measurement includes the elastic deformation of the surface outside the actual indentation (Fig. 5). To throw light on the indentation

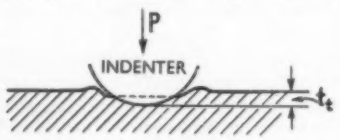


Fig. 5.—Possible form of indentation when measuring the depth.

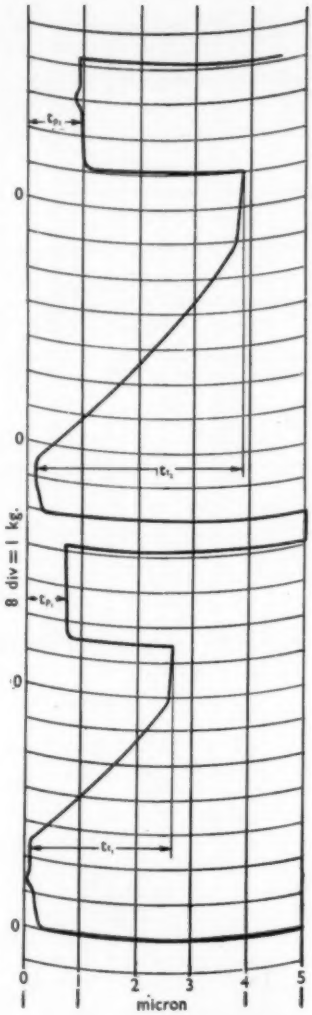


Fig. 6.—Record of hardness test made with increasing load on hardened steel.

in the macro-hardness range, the Hertz formula[2] has been successfully applied by E. Kappler[15] in the case of balls, and by Du Toit-Meyer[16] in the case of Rockwell indenters, but for the micro-hardness range no suitable approach has yet been found.

When re-plotting the recorded curves on a linear scale for a large number of materials, ranging from silver to boron carbide, straight lines have been obtained for the total deformation t_t. The apparatus also allows one to determine t_p in a simple manner. When the desired load has been reached, the weight on the loading beam is brought back to zero and the indenter will assume a slightly higher position, which is t_p, then

$$t_t = t_p + t_e \qquad (8)$$

The dependence of t_t and t_p on load can be shown in a simple way, by loading up to a certain load P_1, determining t_{t1} and t_{p1}; moving the sample to a fresh position, and determining with the higher load P_2, t_{t2} and t_{p2}, and so on up to the highest load: this is shown in Fig. 6 for hardened steel. Re-plotting the results in a linear P/t diagram (Fig. 7) straight lines were obtained, and a

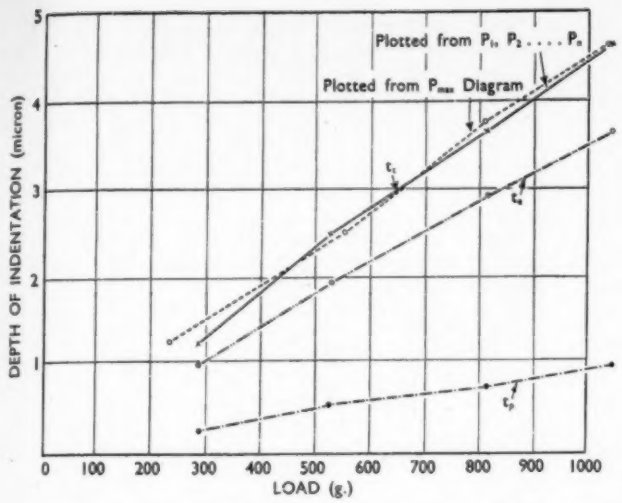


Fig. 7.—The results shown in Fig. 6 replotted on a linear scale together with further results.

re-plotted P_{max} curve conformed with the plotted curve P_1, P_2, etc. In the case of a Nimonic alloy, a slight bending of the curves became apparent, and the P_{max} curve did not conform with the curve P_1, P_2, etc.

The instrument[11] has been further improved by a device for withdrawing the load automatically, so that the plastic deformation of the material tested can also be studied without any hand operation. Furthermore, the behaviour of the material under a standard load can be studied. Such a diagram for steel is shown in Fig. 8. The pre-load was 200 g. which was then increased to 1,000 g. (curve sloping to the right). When the maximum load was reached the recorder paper was still running, producing a vertical line, then after about 17 sec. the load was reduced to the 200 g. pre-load; from this diagram it is obvious that the elastic recovery is not as big as it would have been had no pre-load been applied.

Fig. 9 shows side by side four records of two types of spring steel A and B, tested with the double cone indenter in the direction of rolling (*a* and *c*) and perpendicular to it (*b* and *d*). The differences between these two materials are appreciable, although conventional hardness tests did not show any difference.

The idea behind this method is to carry out the hardness test in a similar manner to the tensile test, for which automatic recording devices have been available for the past 80 years or so for indicating the total deformation in relation to the load or stress applied. The instrument goes even further and shows the dependence of the

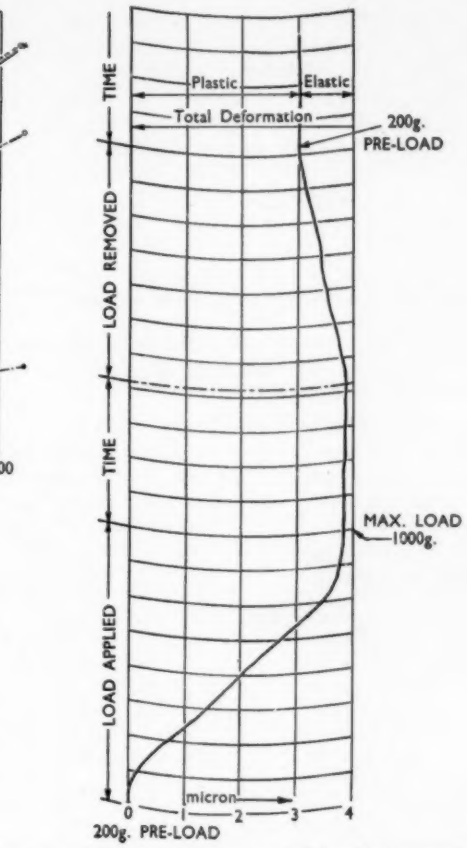


Fig. 8.—Complete loading and unloading record for hardness test on steel. 1 vertical division represents 3·75 seconds and/or 125 g. load.

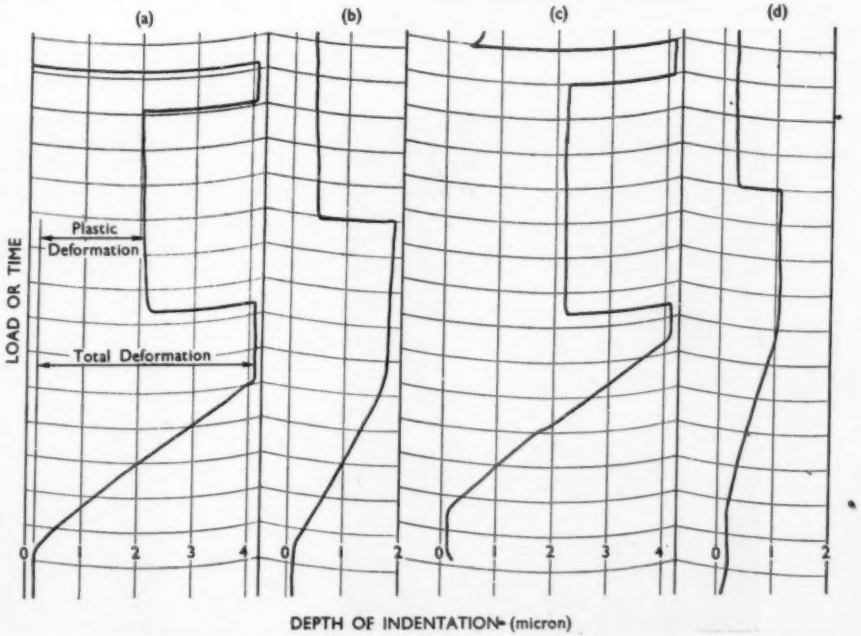
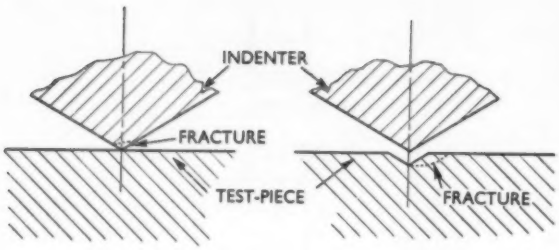


Fig. 9.—Record of hardness tests on two types of spring steel, A and B, tested in the longitudinal, (a) and (c), and transverse, (b) and (d), directions.



(a) (b)

Fig. 10.—Two possible cases of fracture.

properties on time, a factor which is particularly important with plastics: in this way the hardness test becomes a truly rheological test.

Fracture Hardness

Increasing attention has been paid in recent years to the subject of fractography in which fracture faces are studied from the metallographic and mineralogical points of view[17]. A hardness test under certain conditions can produce a controlled fracture and, therefore, supplies a result which can be evaluated quantitatively.

Fractures in hardness tests, in particular micro-hardness tests, are frequently accidentally encountered, and the author has referred to the fact that such damaged impressions should not be utilised for deriving hardness values[18]. This discussion shows quite clearly the reason for this suggestion, as besides the elastic and plastic hardness there must exist a fracture hardness. In a number of investigations, fractured indentations have been shown in micro-hardness tests with square-base diamond pyramids on hard materials[19-22]. The elongated Knoop indenter[23] and the author's double cone indenter[24] were introduced to reduce fracture. However, in a number of investigations with the Knoop indenter fracture zones were shown, and when trying to indent a diamond surface with a Knoop diamond its point fractured. This unlucky incident led the author to further tests with a curved diamond edge on a diamond plane, i.e. to the use of the so-called double cone.

When dealing with brittle materials exposed to a local load by a pyramidal point or a wedge of the same or similar brittle material, there are two possibilities, shown in Fig. 10. In the first instance the point breaks, leaving only a very small indentation, and it might be possible to determine the actual stress along the plane of fracture. Alternatively, an indentation can be made and the walls of the indentation break out along sliding planes or planes of weakness of the metal or mineral.

Both cases have actually been observed. When testing sintered carbides the square-base diamond pyramids frequently break and have to be replaced. Rockwell C-tests with 150 kg. load may also cause the well-rounded Rockwell cone to break, in which case they have to be replaced by Rockwell tests with 60 kg. load.[25]

Reference has been made previously to fractures of indentations reported in the literature, but even the accepted Rockwell-A test can cause a cracking of the indentation and, probably, a deformation of the round shape, as has been shown recently. Fig. 11 shows a photomicrograph of an indentation made on the (0001) face of a silicon carbide crystal by a square-base diamond (Vickers) pyramid under a load of 1 kg. applied for 30 sec. Serious cracking is to be seen, and this has been observed even when the load was reduced in steps, down to 50 g. Such cracks prevent a correct measurement of the length of the diagonal. Fig. 12 shows a group of indentations produced with a 1 kg. load acting for 30 sec. on a double-cone indenter: there is no sign of cracking and the length of the indentation can be measured with reasonable accuracy; furthermore little variation is observed between the different indentations.

In both photographs (Figs. 11 and 12) the actual indentations are surrounded by an area which appears to be shattered, and exhibits what is apparently a thin-film interference pattern. Tolansky thinks that the silicon carbide crystal may have an absorbed surface film of silica which causes this phenomenon, but it has also been observed on other crystals. The cracks of the square-base indentation (Fig. 11) are longest in the direction of the diagonals, and the sub-surface distorted region is roughly a square of considerable extension.

Fig. 11.—Square-base diamond pyramid indentations on silicon carbide. 1 kg. load for 30 sec. × 400

Fig. 12.—Double-cone diamond indentations on silicon carbide. 1 kg. load for 30 sec.

There is, of course, the observation that these zones are similar to the ridges and bulges formed around the indentation of plastic materials such as metals. Only Eppler[26] has tried to derive from them technical information concerning shear strength, which he defined as the ratio of the load in kg. to the area damaged. This seems to be the first attempt at deriving quantitative data from the accidental fracture in micro-hardness tests.

Workers using the Knoop indenter—an elongated pyramid—observed a reduced tendency to cracking, particularly in the direction of the long axis, but still observed occasional sub-surface cracks on brittle materials of high hardness. Thibault and Nyquist[23] classified the materials into six groups, depending on whether sub-surface cracks only, or these combined with fractures of the indentations occurred.

In the double-cone indentations on silicon carbide, the sub-surface distortion is elliptical, and usually of slightly smaller major axis than the length of the indentation. This may be explained by the reduction in stress along the curved edge near the surface. This has the advantage that the sub-surface crack does not affect the measurement of the indentation length used as a convenient measure. Here again the Eppler criterion can be applied; actually the damage in Fig. 12 was determined to be only half that in Fig. 11 indicating that the double cone causes about half the stress and damage. This is an important finding arising out of the study of this new aspect of hardness testing—fracture hardness.

Appendix

The notation used in this article is set out below :—

a	constant in Meyer equation.
C	constant.
c	constant.
d	length of diagonal in diamond pyramid indentations, measured in mm. or micron; in general length of an indentation; area of indentation expressed as kd^2.
H	hardness value as a stress in kg./sq. mm.
H_{max}	maximum hardness value of a material in kg./sq. mm.
H_∞	hardness value independent of load ranging from a medium load to infinite load.
h	hardness (according to the author) as load in g. or kg. causing a certain deformation expressed in unit of length or depth.
k	see under d.
l	exponent.
n	Meyer factor, exponent $n = tan\ a$.
P	load in kg.
P_o	maximum load in kg. which does not cause plastic deformation.
t_t	total depth of indentation in micron.
t_e	elastic depth of indentation in micron.
t_p	plastic depth of indentation in micron.

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Materials for Gas Turbines

Dr. Sutton's Survey at Productivity Conference

At the Production Exhibition and Conference organised by the Institution of Production Engineers and held at Olympia, a number of papers on aspects of "Scientific Research and the Changing Pattern of British Industry" were presented by experts in various fields. Dr. H. Sutton, Director, Materials Research and Development (Air) at the Ministry of Supply, reviewed the progress, particularly in this country, of the search for materials suitable for use in gas turbines. A slightly abridged account of Dr. Sutton's survey is presented here.

FROM the early days of its conception, the gas turbine has depended upon high temperature materials for its effective development. Despite this, great progress has been made in a comparatively short period in relation to other well-known groups of engineering materials.

The parts of the gas turbine which have presented the main problems for the metallurgist are :—

(1) the rotor blades of the turbine;
(2) the rotor disc or drum;
(3) the nozzle guide vanes and stationary blades; and
(4) the combustion chamber and discharge arms;

but other parts provide much scope for the efficient handling and application of high performance materials, e.g. compressor blades, rotors and casings; heat exchangers, where these are used; and shafts and bearings. The gas turbine presents a unique opportunity for the designer with his mechanical engineers; for the specialists on thermodynamics, etc.; for the materials and component manufacturers; for the metallurgists who evolve and develop the materials to be used; and many others. Probably no other manufactured product embodies the integrated efforts of so many scientists and technicians.

The first problem, as far as service aircraft were concerned, was to develop the materials that would at least satisfy the following :—

(1) The alloy should not give an extension of more than 0·1% in 300 hours under a stress of 3 tons/sq. in. at 750° C.

(2) The alloy should be sufficiently workable for certain somewhat complicated forgings to be produced in it without excessive difficulty.

(3) The alloy should have the highest possible resistance to oxidation and other corrosive attack at 750° C.

It was, of course, appreciated that other temperatures and stresses would be likely to be concerned, and this proved to be the case. As regards resistance to oxidation, many materials, including nickel-chromium alloys, were known to be very resistant for long times at 750° C. and, provided that there was no danger of impingement by burning gases at excessively high temperature, no difficulty in meeting that requirement was anticipated. It was appreciated that the raw materials for production of turbine blades, etc., must not be extravagently expensive and must be available in fair quantity of sufficiently consistent and reliable quality.

Nickel-Base Alloy Work

The known features of alloys containing, apart from small amounts of impurities, about 80% of nickel, and having the rest substantially of chromium, made them attractive for research. The solubilities of additional elements, and the influence of solution treatments and ageing or precipitation treatments at various temperatures were studied. It was quickly discovered that carbon and titanium contents with particular heat-treatments could be used to secure considerably improved mechanical properties, at high temperatures. These studies of the effects of added elements, their solubilities, the manner and rate of precipitation at various temperatures, proved a fruitful field, and the work progressed in such a way that the target originally set (0·1% creep strain (max.) in 300 hours at 3 tons/sq. in. at 750° C.) was comfortably met and exceeded. The modern form of the 80/20 nickel-chromium alloy with small additions of titanium and aluminium, Nimonic 80A, is expected to give not more than 0·1% creep strain in 300 hours at 12 tons/sq. in. at 750° C., or in 1,000 hours at 9 tons/sq. in.

Early Developments

By the middle of 1941 the first alloy of the series, Nimonic 75, had developed to a state at which it was a practical proposition to produce a large disc forging and sheet material for combustion chambers, also tubes. The important aspects of materials for the intended purposes—stability and durability under conditions of use, ease of fabrication, machinability, suitability for quantity production—were examined very closely. While the first type of alloy to be developed, Nimonic 75, proved to be of special interest and suitable for sheets for flame tubes, and other applications for which it has since been supplied and used in quantity, attention and effort were naturally focused on the second type of alloy developed, now known as Nimonic 80 or Nimonic 80A. The original criterion of 3 tons/sq. in., 300 hours, 750° C., for not more than 0·1% specific creep strain was followed by demands for greater resistance to stress at 650° C. Further research and development work brought out the merits of high temperature solution treatment, the value of suitably combined additions of small amounts of titanium and aluminium, and the importance of selecting the precipitation or second-stage heat-treatment to suit the temperature at which the material would be used under stress in service. Production of turbine blades as die forgings in Nimonic 80 was under way in January, 1943, following developments on blades machined from bar.

The properties of the Nimonic 80 and 80A continued to progress with increasing experience. The currently expected properties in Nimonic 80A and Nimonic 90 are indicated in Tables I and II. Nimonic 90 is similar to Nimonic 80 and 80A alloys, but contains about 20% of cobalt, by which substantial advantage to strength or working temperature, or both, is achieved. An important quality in alloys for moving blades, stationary blades, flame tubes and other parts is resistance to thermal shock, and in this connection the Nimonic alloys have given good service.

Other Non-Ferrous Alloys

Cobalt base alloys, usually containing about 30% of chromium and about 6% of tungsten, have been used for nozzle guide vanes, and have been produced as castings, mainly by precision-casting techniques in investment moulds. At present, cast moving blades are not in general use in British aero-turbine engines, mainly owing to the difficulty in ensuring that each casting is free from casting defects, but also to the fact that higher fatigue properties have hitherto been obtainable consistently in wrought materials. Although Nimonic 80 was not designed or developed for use in cast forms, remelted alloy has been precision cast and used effectively in nozzle guide vanes by several British engine firms.

Further research led to the development of an alloy for rotor blades containing about 19% of chromium, 12% of nickel, 45% of cobalt and small additions of other elements. This material has good properties at 700–850° C.

Steels for High Temperature Service in Gas Turbines

Austenitic steels are of particular importance for parts of industrial, marine and aero-turbines. An austenitic, chromium-nickel-niobium steel has been studied and the results suggest that heat-treatment is a factor of greater influence than grain-size *per se* in relation to creep performance at high temperatures. Four austenitic alloys are finding application in blading for long-life gas turbines. The results of creep tests up to 10,000 hours' duration show that extrapolation of data from 300 to 1,000 hour creep tests to indicate

TABLE I.—STRESSES FOR SPECIFIC CREEP STRAIN OR FRACTURE.

Material	Temperature °C.	Time hr.	Stress (tons/sq. in.) for Strain of			Stress to Fracture tons/sq. in.
			0·1%	0·2%	0·5%	
Nimonic 80A	750	300	12·0	13·5	14·5	15·0
		1,000	9·0	10·5	11·6	11·5
Nimonic 90	750	300	14·5–15·6	16·0–17·2	17·0–19·0	17·5–19·6
		1,000	12·0–12·4	13·5–14·0	14·5–15·8	15·0–16·3
	815	300	8·0	9·0	10·0	10·5
		1,000	6·0	7·0	7·5	8·0

TABLE II.—DIRECT STRESS FATIGUE.

Material	Temperature °C.	Time hr.	Stress Range tons/sq. in.
Nimonic 80A	750	300	± 15
Nimonic 90	750	300	± 16·7–17·0
	815	300	± 12·2

performance after longer periods may be very misleading.

Although ferritic materials for gas-turbines discs have been under investigation in Great Britain since 1944, it was not until fairly recent years that they came to be extensively used. Of the austenitic materials which were used, the most popular was G18B. It is now usual to use ferritic steels for discs of aero-turbines for several reasons, the principal ones being the high proof stress and general strength properties attainable, economy of strategic metals, ease of manufacture, and lower cost than austenitic steels and alloys. The higher thermal conductivity and lower thermal expansion are also, in general, of advantage. The ferritic disc steels used are of several types, having alloy contents from less than 1% to about 13%. Popular types are carbon-molybdenum, molybdenum-vanadium, chrome-molybdenum and high chromium. These steels are hardened by cooling in air or oil from a fairly high temperature, e.g. 1,100° C., and tempered at a temperature higher than those to be encountered in service. The high chromium type has the advantages of improved resistance to scaling in service, and to corrosion during storage, compared with low alloy steels.

It had been known for a long time that the hot strength of ferrite is increased in moderate degree by manganese, and more powerfully by molybdenum. Research on the carbides precipitated in alloy steels tempered at 650° C. for long periods, followed up by studies of creep properties of alloy steels in relation to their constitution, has shown the powerful effect of vanadium carbide (VC) in ferritic steels. Heat-treated steels of suitable compositions have a bainitic structure containing VC in a finely divided condition, and the particles appear to be very reluctant to coalesce at temperatures up to 650° C. Other carbides, e.g. chromium carbide Cr_7C_3, tend to coalesce at such temperatures and creep resistance diminishes.

A great number of stator blades has been produced as precision castings in H.R. Crown Max and similar high alloy steels. Large castings, e.g. diffuser casings and nozzle guide rings, in similar heat and corrosion-resisting steels, have been made in large numbers as centrifugal castings. Shell moulding has been used for castings of various types and use of this technique appears likely to increase. Ring-shaped pieces are also made by rolling from pierced billets, or by forming from extruded or rolled sections and completing the ring by a butt-weld.

Heat exchangers of industrial gas turbines demand reasonably cheap but durable material for the tubes, particularly where reheat is used, temperature and corrosion being the main factors; vanadium residues from the products of combustion of some oils aggravate the damage seriously.

Other Materials

In aero-turbines, wrought aluminium alloys have been used extensively for rotors, discs and blading of compressors. Aluminium alloy castings are used in miscellaneous other parts.

Magnesium-rich alloys are used for castings of moderate to large size for compressor casings and other parts. The modern types of alloy containing zirconium and rare-earth elements have proved of particular advantage, because of the remarkable soundness achievable, and the improved creep resistance of these alloys at raised temperatures relative to earlier alloys.

General Features of Materials for Gas Turbines

Although the requirements are particularly exacting, and there is so much to be gained by improved performance, materials for gas turbines must be reasonably available in respect of both quality and cost. The expenditure involved in developing an engine material and taking it through all the stages which lead, in some cases, to eventual use in production engines is very high, and there are quite enough difficulties outside the problems of supply of raw materials.

It is of first importance that materials for gas turbines shall be good engineering materials in the generally accepted sense of the term, as well as having the desired properties at particular temperatures called for by the special conditions of use. Not all the properties can be controlled to give the desired degree of amenability to the usual metal fabrication and handling techniques.

The materials which are subject to high temperatures must possess a substantial degree of stability at those temperatures, and preferably some margin for accidental exposure to even more severe conditions without catastrophe. They must be reasonably stable in respect of resistance to oxidation; in retention of strength, creep and fatigue properties; in dimensional characteristics; and in resistance to cracking under repeated thermal stressing.

The alloys which have found extensive use as moving blades are all characterised by development of their useful properties by a high temperature heat-treatment followed by a treatment or treatments at lower temperatures, the first treatment causing some constituents to go into solution, and the later treatment or treatments causing partial " precipitation " of one or more of these special constituents from solution. It is important that there should be little further change under operating conditions and a feature to be kept under observation is the tendency for stress to hasten " precipitation " in some cases.

In the early days of gas turbines, there was some optimism about apparent creep resistance or absence of creep during creep tests of particular alloys at high temperature under stress. This was found to be due to a tendency of particular alloys to shrink on reheating to lower temperatures after being heat-treated at an appreciably higher one, whether stressed or not. Low thermal expansion enables use of small clearances and reduces risk of distortion under non-uniform heating. The lower the specific gravity of a blade material, the better, since the main stress is centrifugal.

Present designs of gas turbine blade have a complicated section with taper, twist and other features which present problems for the production engineer. It is usual to make rotor blades from forgings, but many have been machined from bar, especially those of the smaller sizes. Forgeability is not easily attained in materials designed for high strength at high temperatures, and it is to be expected that forging temperatures will be substantially higher than operating temperatures in service. It has been usual to forge blades oversize and finish them by machining; much effort has been expended in development of techniques for precision forging so as to leave the aerofoil part of the blade requiring only a polish, but the problems involved in securing surfaces free from contamination and manufacturing defects, and the cost and numbers of forging dies, have been major drawbacks to full-scale operation.

Castings in heat-resistant alloys for rotor blades have generally proved to be less reliable in service than the wrought materials, but if operating temperatures continue to rise as they have in recent years, a position may be reached at which the alloys that will be required may have to be produced as castings or as sintered products. At present operating temperatures, higher fatigue strengths are achieved in the wrought alloys than in the castings, in materials of which there is experience in both forms. Vacuum melting and casting of high temperature alloys is showing some promise of yielding castings of improved quality, and, at this stage, it would not be wise to assume that castings in suitable alloys and of high quality will not come into favour for rotor blades.

The higher operating temperature in the hot zones of modern aero-turbines have made thermal shock resistance a matter of greater significance and difficulty, and have probably lessened the prospect of utilisation in high performance engines of many materials which have been considered for use at high temperatures and which have many attractive features but not very good resistance to thermal shock, e.g. carbide alloys containing some 30% by weight of metallic bonding.

Machinability

Machinability is obviously a very valuable quality of any material from which parts of gas turbines are to be made. The alloys used vary greatly in machinability. It is possible, in heavy cutting operations, to produce strains in the material near the surface which have an injurious effect on the finished component, and care must be taken that cutting in finishing stages shall be clean, and not such as to disturb material near the surface. From forged blades, material which has been affected by oxidation or contaminated in any way must be removed completely during the machining. Vapour blasting and hand polishing are commonly used for finishing blades and other components.

Most of the wrought high temperature materials are amenable to welding, and a considerable amount of the sheet metal work in alloys and heat-resistant steels is fabricated into components with the use of welding. Fusion and resistance welding techniques are used. Oxy-acteylene, carbon-arc, argon-arc, metal-arc, and inert-gas-shielded metal-arc processes and the various resistance welding techniques are used as required. The accuracy to which the parts have to be made as regards form and dimensions is higher than normal, and calls for high manipulative skill. Attachment of blades to discs by welding has been investigated both in U.S.A. and in the U.K., but in aero-turbines there has been difficulty in avoiding appreciable stress concentrations which lead to cracking. The mechanical damping afforded by conventional blade fixings is thought by many to afford worthwhile advantages.

Future Trends

If operation at higher temperatures is required in future years, it seems clear that either yet further improvements in alloys for the hotter regions must be achieved, or that means of cooling the components will be necessary.

With any type of alloy or steel which has been under development for some years, there tends to develop a position from which further gain of properties at high temperature is achievable only by a vast expenditure of effort, or by sacrifice of some quality of the material, e.g. resistance to impact. The improvements gained by accumulation of experience in producing the metals themselves, in making, melting, casting and manufacturing alloys of known types, have been very gratifying to all concerned. Further advances of known types are likely to be achieved.

It seems possible, however, that the use of elements which are not so attractive from the points of view of world strategy, availability, or economy may come more prominently into the field. Molybdenum-rich alloys appear likely to merit consideration for use at temperatures upwards of 1,000° C., if a satisfactory method of protecting the surface from oxidation, etc., can be devised, an important requirement being that the protective effect shall persist even though the component be subjected to high temperature, stress and strain.

Bonded carbides, borides, silicides, etc., that have been investigated as far as the stage of trials in engines appear to have been rather brittle and liable to suffer damage at corners, sharp edges, etc., during ordinary workshop handling, and some have shown rather poor resistance to thermal shock. It will be safe to assume that the best has not yet been achieved in this field.

Sintering technique for preparation of high temperature metals in useful forms from powder have long been used for tungsten, molybdenum and others. There has been much experimentation and development in connection with iron alloys and other alloys for use at high temperatures. Sintered and infiltrated iron-copper alloys have been manufactured into compressor blades on a considerable scale. Sintered carbonless Vitallium (64 Co : 30 Cr : 6 W) has also been prepared, the product being of high quality. The general mechanical properties were good, but creep resistance at 600° C. or higher was not so good as that of the carbon-bearing cast alloy.

The quest of hollow blades for application of cooling, and also for light-weight stiff stator blades has stimulated development of these blades by powder metallurgy, by casting techniques, in solid wrought forms, and by fabrication from sheet, strip, tubes, etc. Sintered blades having cooling passages (0·030 in. or 0·040 in.) suitably disposed within the blades and passing from root to tip have been described.

Titanium-rich alloys appear likely to prove of advantage in compressors for aero-turbines in regions at which temperatures up to 400° C. are concerned, and possibly for service at higher temperatures in future years. Uses envisaged, and under development, are blading and discs of compressors. Sheet alloys are likely to find application in other parts of engines and ancillary equipment that are not subjected to very high temperatures in service.

There is great interest in porous bodies prepared by sintering and other techniques for transpiration cooling, and it is to be expected that, with increasing experience, these bodies will find useful application in turbine-engines. There are applications in view in which the cooling fluid not only diminishes attack by harmful gases as a result of the cooling effect, but also tends to prevent accumulation and adherence of harmful deposits.

Cladding techniques by which a layer of more resistant materials is applied to one or both surfaces of sheets of less expensive material have been developed and clad steels and copper have been produced. These materials are receiving a good deal of attention.

Railway Rolling Stock Bearings

Lining by Pressure Casting Technique

CONSIDERABLE developments have taken place in recent years in the method of white-metalling the bearings of railway rolling stock and others of a similar type, and today pressure casting is rapidly superseding the old method of pouring by hand the white-metal strip forming the bearing surface, with its attendant drawbacks of blowholes and porous material. Fig. 1 shows two interesting combined plants for such pressure casting made by the Monometer Manufacturing Co., Ltd., London, which are in use at the Shildon Works of British Railways, where the production of bearings is in the region of 1,400 per week.

Typical bearings for rolling stock can be seen in the illustrations, the most usual sizes being 9 in. long × 4½ in. diameter, and 10 in. long × 5 in. diameter. They consist of a " brass " casting with a semi-cylindrical concave surface along which is machined a longitudinal dovetailed slot which forms an anchorage for the bearing metal lining. The composition of the main casting is: 6–8% tin, 1–3% lead, 4–6% zinc, not more than 1% nickel, and the remainder copper. A typical analysis of the white metal used for lining the " brasses " is: 56% tin, 30% lead, 11% antimony and 3% copper.

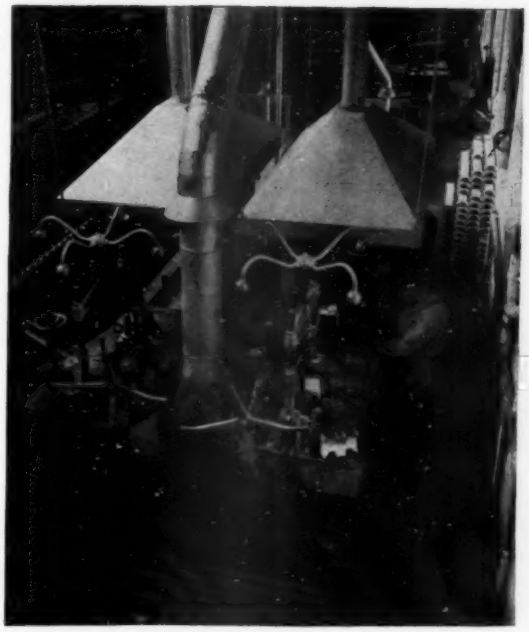


Fig. 1.—View of the dual Monometer plants taken from the pressure casting end.

Machining

The rough casting is first shot-blasted, ground on a disc grinder to gauge, and the back milled on a vertical miller (speed 360 r.p.m., and feed 12 in./min.). In this operation, the bearing is located from the inside face which is later to be filled with white metal, this location determining the thickness of the brass casting, which is important as controlling the amount of white metal required for the actual pressure casting. The casting is next bored and faced on a special machine, the pieces being mounted in a jig and machined in pairs (spindle speed for boring 392 r.p.m., and feed 0·016 in./rev.; speed for facing the ends 132 r.p.m., with hand feed). The next operation is to drill three small breather holes in the back of the casting to allow for the escape of air when pressure casting. This is done on a driller with a special head mounting three drills (spindle speed 1,150

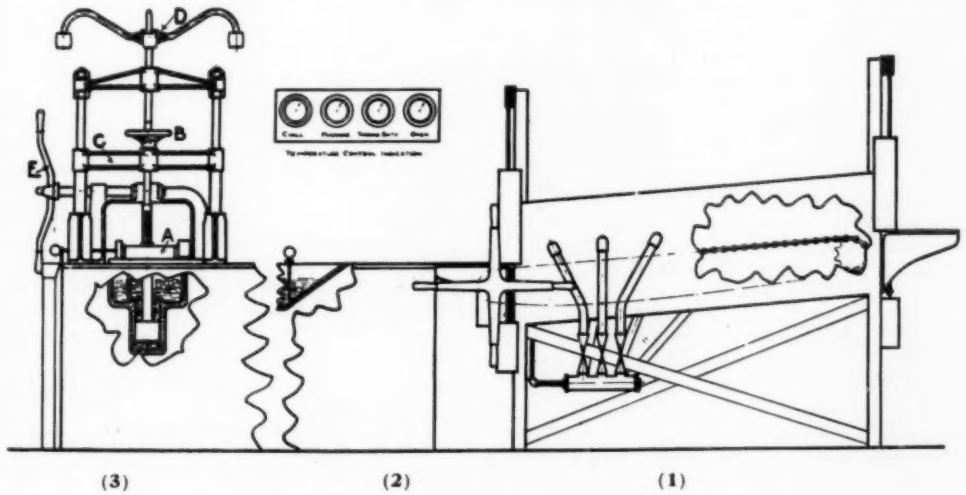


Fig. 2.—Sectional view of pressure casting plant.

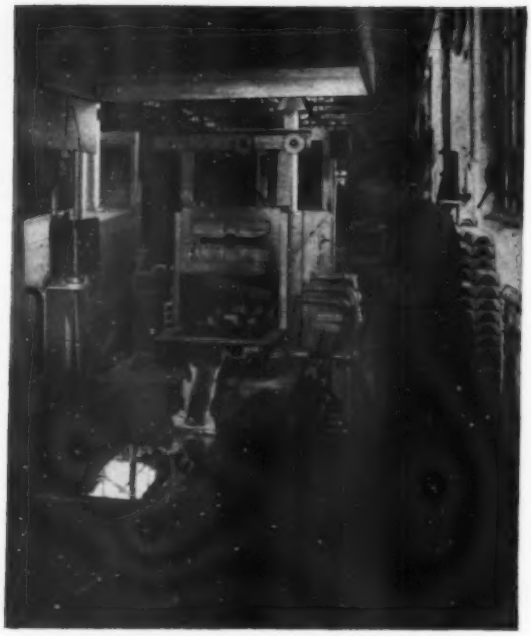


Fig. 3.—View of preheating oven and tinning bath.

r.p.m., and feed 0·005 in./drill rev.). The dovetailed recess already mentioned is finally machined on another vertical miller equipped with a tungsten-carbide tipped rose-bit cutter.

White-Metalling

The design of the Monometer plant for white-metalling can be followed by reference to the sectional view, Fig. 2, from which it will be seen that a plant comprises three units: (1) the preheating oven; (2) the tinning bath; and (3) the pressure casting machine. All these are heated by natural draught burners operating on gas at ordinary mains pressure, each set of burners being supplied from a pressure-equalising chamber, and each of the three units comprising the plant being under separate automatic control for temperature.

The " brasses " are first painted on the surfaces which have not to be tinned with a mixture of French chalk and water, to which a little isinglass has been added to prevent rubbing off, and then placed in the preheating oven, which is equipped with a chain conveyor hearth operated by handwheel at the discharge end, the oven having a capacity of fourteen " brasses." Here they are raised to a temperature of 340°C., fresh "brasses" being inserted through the lifting door at the feed end to replace the heated castings as they are discharged at the exit end on to the work-table. The dovetailed recess is then brushed with Baker's solution (a cleaning and fluxing solution), and any grit or sand removed, after which the casting is submerged in the tinning bath (2), this being automatically maintained around 230° C., with an average gas consumption of 1½ therms per hour. When it has acquired this temperature, the casting is removed by tongs and again brushed, and then passed along to the pressure casting machine (3) and placed in the chill or die *A* carried on the pivoted bridge arm *C* which swings over and locates the " brass " in the chill over the casting nozzle, where it is finally locked by the large upper handwheel *D*, the " brass " being clamped in the lifting box by a small hand lever. White metal is then forced into the dovetailed recess by means of the handwheel *E*, at the side of the machine, which operates the plunger in the melting pot through a rack and pinion. The " brass " is now lifted from the chill or die in the lifting box, swung over the working table, and dropped out by operating the quick-release hand lever.

No subsequent machining of the bearing face is required. The pressure casting machine has a capacity of 200 lb. of white metal, and is suitable for metalling bearings up to 20 lb. in weight, with an output up to 25 lined bearings per hour and a gas consumption of 1 therm hourly. The chill (or die) used is of mild steel, fitted with a lifting box, and is water-cooled, with provision for the use of an endwise indicating pyrometer for taking the chill temperature, which is maintained at 70–95° C.

The sequence of operations and the design and layout of the plant can also be followed from the photographs of the British Railways equipment. In Fig. 1 the pivoted bridge arm on the left is open ready for the insertion of another bearing in the chill. Fig. 3 shows the oven with a bearing just discharged and ready for immersion in the tinning bath.

Humphreys Spiral Concentrator Sales Agreement

THE GENERAL ELECTRIC CO., LTD., announces that its Fraser & Chalmers Engineering Works, which manufactures a wide range of metalliferous mining equipment, has concluded an agreement with the Humphreys Investment Company of Denver, Colorado, to be the selling agent respecting the sales of Humphreys' Spiral Concentrators for delivery to the United Kingdom, Gold Coast, Gambia, Sierra Leone, Nigeria, Burma, India and Pakistan.

The outstanding feature of the spiral is the simplicity of operation and low cost of concentration of minerals. Ground ore, fine coal, sand or other materials to be concentrated or cleaned is delivered with water to the top of the spiral. As the pulp flows down the spiral channel, which has a modified semi-circular cross-section, the heavier particles move in toward the inside of the channel on a band of heavy mineral concentrate, while the lighter particles travel farther out in the channel with the faster-running water. Concentrate is drawn off from concentrate ports located at 120° intervals near the inside edge of the channel. There are no moving parts; floor space per ton treated is very small; and installation, maintenance and operating costs are so low that spirals have effected economical concentration of materials which could not hitherto be worked at a profit.

The size range of material suited to spiral separation depends to some extent on the specific gravity of the minerals present, the grind necessary for their liberation, and the shape of the particles. On suitable material, good concentration is generally made on pulp containing heavy mineral particles between 14 and 200 mesh, with a decreasing recovery below 200 mesh. However, fine coal up to ¼ in., provided the refuse particles are not over 14 mesh, may be cleaned in spirals.

A Humphreys' spiral concentrator has for two years been included in the equipment installed at the mineral dressing laboratories maintained by Fraser & Chalmers at the G.E.C. Wembley Research Laboratories.

Machining Hard Materials

Ultrasonic Equipment Available for Drilling

NEW possibilities for the accurate machining of hard and brittle materials such as glass, ceramics, germanium tungsten and titanium carbides, diamond, synthetic gems etc., have in recent years been opened up by ultrasonics. As a result of development work in this field carried out at the Mullard Research Laboratories, there are now available two ultrasonic drills, one of 50-watt and one of 250-watt power. With the attachment of suitable tools, both these machines can, in addition to drilling, be used for such normal operations as cutting, shaping. hobbing, grinding, polishing, etc. Moreover, since they depend upon a reciprocating instead of a rotary action, they are not limited to the cutting of circular holes but can make intricately shaped holes which would be difficult, if not impossible to machine by more conventional methods.

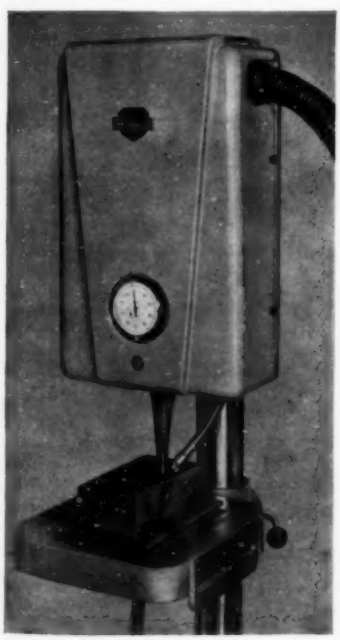
The process also has the advantage that it is not limited to electrically conductive materials, and it causes no deformation, discoloration or burning of the workpiece. Another unique feature is that, should the occasion arise, curved holes can be cut, using as a tool a wire bent in an arc of a circle.

The 50-watt drill is designed for bench mounting, and is capable of machining holes varying from 0·006 in. to $\frac{1}{4}$ in. across and to a maximum depth of $\frac{1}{2}$ in. Greater depths can be considered if special stubs are used. The 250-watt model is a fully-engineered tool suitable for mounting either on existing machine tools, such as verticle milling machines, jig grinders etc., or on a standard pillar-type drill stand. It is capable of machining holes varying from 0·006 in. to 2 in. across, and to a maximum depth of 2 in. The drill head incorporates its own vertical slides which are manufactured to a high degree of precision. A pneumatic drill feed is incorporated which permits very accurate control of cutting. Provision is also made for the automatic periodic retraction of the drill, thus enabling deep holes to be flushed out with fresh slurry. The cutting depth is continuously registered on a micrometer gauge recessed into the head. For automatic operation, the use of a slurry pump is essential, but if the machine is intended for manual operation the slurry can be hand-fed.

Operation and Performance

In both machines, cutting is achieved by the continuous light chipping action of an abrasive slurry interposed between the cutting tool and the surface of the workpiece. The slurry, depending upon the material to be machined, consists of a suspension of silicon carbide or boron carbide in water. The shape of the cut closely follows that of the tool, which is normally made of a soft material such as brass or mild steel. Special hardened tools of the conventional kind are not necessary, so that the user can easily shape a cutting tool to suit any particular requirement. During the machining operation there is no stressing and little heating of the material, and troubles due to distortion and deformation are avoided.

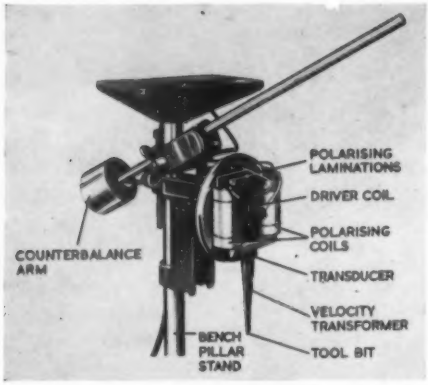
The machining accuracies and surface finishes possible to achieve with these ultrasonic machine tools are basically dependent on the size of the abrasive particles used. Surface finishes of 8 to 10 micro-inches are easily obtainable and finer finishes can be obtained using appropriate abrasives. As with normal machining,



Above—A $\frac{3}{16}$ in. thick tungsten carbide die with an overall slot length of 1 in., cut in 36 minutes using the 250-watt drill.

Left—Close-up of the Mullard 250-watt ultrasonic drill showing how the abrasive slurry is fed to the drill tip.

Right—The 50-watt ultrasonic drill.



Annotated photograph of the 50-watt model drill head.

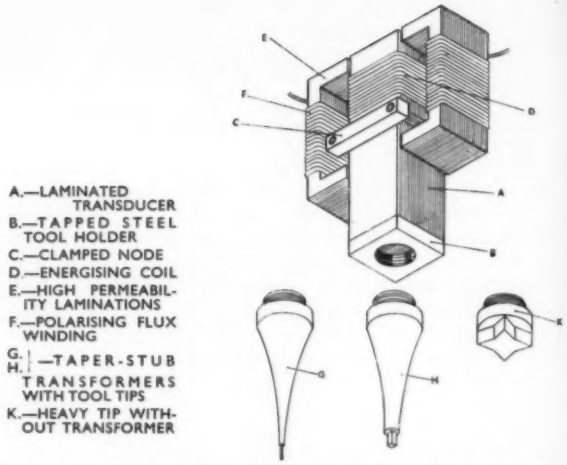


Diagram showing essential features of the 50-watt drill.

a re-passing action equivalent to reaming may be carried out to obtain accurate sizing. In this manner, and using a 1,000-mesh abrasive, it is possible to achieve dimensional accuracies of the finishing cut of the order of 0·0005 in. The dimensional accuracy of the roughing cut, using 120 mesh abrasive, is usually between 0·002 and 0·003 in.

Speeds of working vary according to the materials being worked and the size of the tool used. For example, using the 50-watt drill, a $\frac{1}{4}$ in. square hollow tool will penetrate soda glass to a depth of 1mm. within 30 seconds. A similar penetration into tungsten carbide would take approximately 10 minutes, i.e. a cutting rate of 0·1 mm/min.

The 50-watt Drill

The 50-watt drill is similar to a normal light bench-type power drill, and operates from 110–250V A.C. mains supplies. It comprises two units : the drill head, mounted on a bench stand ; and an ultrasonic power unit, connected by a single 4-core cable. Controls are limited to a simple tuning control and an on/off switch.

The drill head consists of a magnetrostrictive transducer coupled to a brass velocity transformer, or matching stub, to the end of which are screwed the various cutting tools. These are turned with a standard B.A. threaded stud for fitting to the machine, or in the case of complex shapes brazed to threaded studding. Three velocity transformers are provided with each equipment, and have tip diameters of $\frac{1}{2}$ in., $\frac{1}{4}$in., and $\frac{3}{8}$ in. This range of stubs covers all drilling sizes from the smallest possible to the equivalent of a square cutting tool having $\frac{3}{8}$ in. sides. The appropriate stub is chosen to suit the particular size of tool being used.

The transducer, which is a laminated nickel stack, is a 20 kc/s. half-wave resonant section clamped at its nodal point. The drive coil is mounted on the transducer, and separate polarising coils are fitted on a laminated yoke, which flanks the transducer. The brass stubs are also 20 kc/s. half-wave resonant sections and are turned with a $\frac{3}{8}$ in. B.S.F. stud which screws into a stainless steel plate brazed to the face of the transducer. The amplitude of vibration at the face of the transducer if of the order of 0·0005 in., and the three stubs magnify this movement in the ratio 2 to 1, 3 to 1 and 6 to 1, giving tip amplitudes of approximately 0·0001, 0·0015 and 0·003 in. respectively.

The drill stand is of conventional type with the drill head mounted on a lever-operated, counter-balanced fitting which slides on a vertical pillar.

The power unit has an ultrasonic output of approximately 50-watts at a nominal frequency of 20 kc/s. for energising the transducer, and also provides a D.C. polarising supply. The circuit comprises a free running symmetrical multivibrator whose frequency may be tuned between approximately 16 and 24 kc/s. The output is fed into a single amplifying stage which drives two output pentodes in parallel. Connection to the transducer is made via an output matching transformer. The low voltage polarising supply is provided by a full-wave rectifier circuit. A metal tray to fit the base of the drill stand may be supplied to contain the liquid slurry used on the work. Special matching stubs, for example to be used when deep cutting is done, may be made to special order. Cutting tools are not supplied with the equipment but are simply made by the user.

The 250-watt Drill

The 250-watt model comprises three units : a drill head which incorporates the precision vertical slides and pneumatic feed control ; an ultrasonic generator ; and a control panel. The equipment operates from A.C. mains supplies in the range 200-250 volts at 45-65 c/s. A compressed air supply of 60 lb./sq.in. having a flow of 7 cu.ft./min. is also required.

The electrical design of the drill head is basically similar to that of the 50-watt machine. For driving the transducer, however, a standard Mullard Type E7590 low frequency ultrasonic generator is used, connected to the control unit by means of a 5-core cable. The control unit is mounted on a pedestal and houses the electronic and pneumatic controls and indicating instrument. This unit is connected to the drill by means of a single reinforced flexible coupling, through which the power supply cables and compressed air are fed.

BUILDING operations have commenced on an extension to the Birmingham factory of Rapid Magnetic Machines, Ltd., which should be completed in six months time. The extension has been necessitated by the expanding market which the Company, the oldest in its specialised field, continues to enjoy.

NEWS AND ANNOUNCEMENTS

Advanced Metallurgical Courses

BESIDES the chemical and metallurgical courses intended to meet the needs of candidates for Ordinary and Higher National Certificates, and the examinations of the City and Guilds of London Institute, the Royal Institute of Chemistry and the Institution of Metallurgists, Northampton Polytechnic is organising a number of special advanced lecture courses on the following topics: Materials of Construction; Heat Transfer, with special reference to Fuel Technology; Recent Developments in Metal Finishing; Corrosion and Packaging; Chemical and Metallurgical Thermodynamics; and Refractories, their Manufacture, Properties and Uses. In conjunction with last course, a laboratory course in refractory technology will be organised for the Spring Term, 1955. Other courses include: Engineering Chemistry and Engineering Metallurgy; Clay Technology; Glass Technology and Glassblowing; and Scientific German. Further particulars may be obtained from the Principal, Northampton Polytechnic, St. John Street, London, E.C.1.

Institute of Fuel Special Study

THE Inaugural Conference of the Institute of Fuel's Special Study of Sulphur Removal and Recovery from Fuels will be held at the Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1, on Wednesday and Thursday, 6th and 7th October, 1954. Following an introduction to the subject by Dr. A. Parker, who will speak on "Social and Industrial Consequences of the Presence of Sulphur in Fuels," there will be presented some dozen papers grouped into such general topics as the effect of sulphur in the iron and steel industry; the occurrence of sulphur in British coal and its removal; the occurrence of sulphur in town and coke-oven gas and its removal; new techniques for the removal of sulphur from fuel gas; sulphur in petroleum; and sulphur requirements of industry.

Further particulars can be obtained from the Secretary, The Institute of Fuel, 18, Devonshire Street, Portland Place, London, W.1.

Technical Meetings in Paris

THE IIIe Salon de la Chimie et des Matières Plastiques, which, as already announced, will be held from 3rd to 12th December at the Porte de Versailles, Paris, will be the meeting place for a number of international conventions—the "Technical Meetings in Paris." Specialists in many fields have already signified that they will attend, and the meetings will, therefore, undoubtedly provide a most useful forum for the interchange of information.

The most recent developments in the production of basic chemical raw materials, their processes of manufacture and methods of use will be the general subject of the series of lectures and discussions. Specialists in various branches of each field will take part, and members will lunch together at each daily session. These meetings will be divided into the following groups: New Vacuum Techniques; Perfumery and Cosmetics; Chromatography and Ion Exchange; The Applications of Microscopy in Chemistry; Antifouling Paints; Electronic Techniques in the Service of Chemistry; Control and Regulation Systems in Sugar Refineries; Recent Developments in Plastics; and Corrosion.

At the Salon de la Chimie there will be a larger number of exhibitors than last year. In most sections new developments on show will be of great interest to production chemists and engineers.

Chemists, technologists, engineers and industrialists who wish to attend the "Technical Meetings in Paris" can obtain a detailed programme on application to the Secretariat du Comité d'Organisation, 28, rue Saint-Dominique, Paris, 7.

Marking of Imported Wire Goods

THE Standing Committee appointed by the Board of Trade will hold a Public Enquiry at the Board of Trade Offices, Horse Guards Avenue, London, S.W.1, on Wednesday, 17th November, at 10.30 a.m., and, if necessary, on Thursday, 18th November, to consider whether imported wire goods used for domestic and catering purposes should be required to bear an indication of origin. The Board of Trade announced on 8th April, 1954, that it had been asked to recommend the making of an Order-in-Council on this subject and had referred the request to the Standing Committee. Communications regarding the Enquiry should be addressed to the Secretary, Merchandise Marks Committee, Board of Trade, Horse Guards Avenue, London, S.W.1.

Electro-Chemistry Lectures

ORGANISED by the Department of Extra-Mural Studies of the University of Liverpool, a post-graduate course of twenty lectures dealing with Modern Developments in Electro-Chemistry will be given by Dr. A. Hickling, F.R.I.C., Reader in Physical Chemistry in the University. Intended as a refresher course for graduates in chemistry, metallurgy, or engineering, and persons of comparable qualifications working in this field, the course will be directed primarily to the study of the mechanism of the processes occurring at electrodes during electrolysis. This is a field in which considerable advances have been made in recent years, and it is at the electrodes that most of the problems arise which are of interest in the operation of technical electrochemical processes.

The fee for the Course is £4 4s., and the first lecture will be given at 6 p.m. on Friday, 8th October, 1954. Further particulars may be obtained from the Director of Extra-Mural Studies, 9, Abercromby Square, Liverpool, 7.

Foundry Advisory Service

THE Association of Bronze and Brass Founders has inaugurated an Advisory Service to promote improved efficiency in foundries by increasing production and reducing costs. Assistance will be given on such aspects as foundry layout and equipment; foundry practice; general technical problems; and costing. The service is available to any bronze or brass founder, whether a member of the association or not. All applications—which should be made to the Secretaries, Heathcote and Coleman, 69, Harborne Road, Birmingham, 15—are

treated confidentially, and fees, which are nominal, are agreed in advance.

Area meetings for the development of the service and of topics of general technical interest are held from time to time in the following regions: London; Midlands (Wolverhampton); Lancashire (Manchester); Yorkshire (Leeds); N.E. Coast (Newcastle-upon-Tyne); and Scotland (Glasgow).

Corrosion Advice Bureau

THE British Iron and Steel Research Association has formed a Corrosion Advice Bureau in order to deal adequately with the numerous enquiries that are received for advice on the prevention of corrosion of ferrous metals. The Bureau will be situated at 140, Battersea Park Road, London, S.W.11. (Tel.: Macaulay 5511). J. C. Hudson, D.Sc., D.I.C., A.R.C.S., F.I.M., has been appointed Head of the Bureau and E. E. White, F.R.I.C., Secretary. W. H. J. Vernon, O.B.E., D.Sc., Ph.D., D.I.C., F.R.I.C., F.I.M., has been engaged as consultant. The services of the Bureau will normally be free to members of the Association, and will also be available to others on a fee-paying basis depending on the extent of the investigations required.

Microscope Exhibition

"THE Microscope in Industry and Research" is the title of an Exhibition, organised by W. Watson & Sons, Ltd., which is to be held in the Milton Hall, Deansgate, Manchester, from 20–25th September, inclusive. The hours of opening will be 10.30 a.m. to 7.30 p.m. on the first five days, and 10.30 a.m. to 2 p.m. on the Saturday.

Personal News

MR. J. F. B. JACKSON has relinquished his position as Director of the British Steel Castings Research Association in order to join the Board of A.P.V.-Paramount, Ltd., as Director in Charge of their new Foundries producing castings in special steels and non-ferrous alloys, which were opened at Crawley, Sussex, early last year. Mr. Jackson was formerly Chief Metallurgist (Foundries), David Brown & Sons (Huddersfield), Ltd, a position he gave up in 1950 to become the first Director of Research to the British Steel Founders' Association, and, subsequently, with the change in status, Director of the B.S.C.R.A.

MR. J. S. MORTON, D.F.C., has been appointed a Director of Electro-Chemical Engineering Co., Ltd.

THE APPLEBY-FRODINGHAM STEEL COMPANY, Scunthorpe (Branch of the United Steel Cos., Ltd.) announces the appointment of MR. A. JACKSON, General Works Manager, as a Director of the Appleby-Frodingham Steel Company. Mr. Jackson, who joined the Company in 1920, has been a member of the Council of the Lincolnshire Iron & Steel Institute since 1933, and was a Vice-President for many years before being elected President for 1950 and 1951. He was awarded the Williams Prize of the Iron and Steel Institute in 1942.

THE WELLMAN SMITH OWEN ENGINEERING CORPORATION LTD., anounces that MR. C. J. BARKER has been appointed General Managing Director of the Company, and that Mr. F H. Brooks has been appointed Managing Director in Charge of Production and Technical Development.

MR. G. GRIFFITHS will be in charge of the new Birmingham Office of General Refractories, Ltd., at The White House, 111, New Street, Birmingham, 2. He will be assisted by MR. W. M. AIKMAN, the younger son of the London Manager of the Company. MR. G. G. ABRAHAM has been appointed to represent the Company in the Middlesbrough Area in succession to the late MR. C. RAMSDEN.

MR. C. E. SLADE has left the service of Philips Electrical, Ltd., to start a practice as a Consulting Engineer specialising in resistance welding. His address is 11, Trowlock Avenue, Teddington, Middlesex.

MR. E. C. VORLANDER has been appointed Managing Director of Honeywell-Brown, Ltd. Mr. Vorlander, who will have his headquarters in London, was formerly Administrative Assistant to MR. T. MCDONALD, Executive Vice-President of the parent organisation, Minneapolis-Honeywell Regulator Company. MR. V. D. MACLACHLAN continues as Director and General Manager of Honeywell-Brown, Ltd.

MR. F. E. W. LAURIE has relinquished his position as Western Branch Manager of the Regent Oil Co., Ltd., to take up duties in the General Sales Division at Head Office. He is succeeded as Western Branch Manager by MR. H. J. TANNER, former North Western Branch Manager. MR. A. B. MUMFORD, until recently Divisional Manager, Avonmouth, succeeds Mr. Tanner. MR. W. H. GOODHIND has left the Regent Company to become Manager of the Supply and Distribution Department of the Caltex Trading and Transport Co., Ltd. MR. K. POTTER succeeds Mr. Goodhind as Manager, Industrial and Automotive Lubricants Department. Other Regent appointments include: MR. R. D. CRANFIELD as Divisional Manager, Avonmouth; MR. S. H. TROTT as Divisional Manager, Liverpool; MR. J. H. WILLIAMS as Divisional Manager, South Wales; and MR. J. FORSHAW as Divisional Manager, Exeter.

THE Aluminium Development Association Research Scholarship in the use of light alloys in structural engineering for the year 1954 has been awarded by the Council of the Institution of Structural Engineers to MR. E. M. JUBB.

MR. P. R. DUNN, Deputy Chief Engineer of British Insulated Callender's Cables, Ltd., has been appointed Chairman of the Mersey and North Wales Centre of the Institution of Electrical Engineers.

MR. R. G. BRAITHWAITE, Director and Welding Consultant to Braithwaite & Co. (Structural), Ltd., has been installed as President of the Institute of Welding in succession to MR. A. R. JENKINS. MR. R. E. G. WEDDELL, Joint Managing Director of W. G. Allen & Sons (Tipton), Ltd., has replaced Mr. Braithwaite as Vice-President.

Obituary

WE regret to announce the death, at the age of 60, of MR. F. W. WOODFIELD, Manager of the Manchester Office of Babcock & Wilcox, Ltd. Mr. Woodfield, who was well known in engineering circles, was a past Chairman and Member of the Technical Advisory Committee for the Fuel Efficiency Exhibition and an active member of the Engineers Club. He joined Babcock & Wilcox in 1929 and was appointed to the Manchester Office in 1935. He was for many years a Director of Erith's Engineering Co., Ltd.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

New Epoxide Resin

A NEW type of epoxide resin now being made at Southampton will further extend the use of this remarkably versatile class of resins. Applications range from the gluing of precious stones in their settings to the making of massive castings weighing ½-ton or more, which are so hard, tough and stable that they can replace metal tools for pressing sheet steel; from the manufacture of durable chemical-resistant structures with glass fibre reinforcement to low-cost, long-wearing and accurate foundry patterns cast cold in plaster moulds. Specific advantages claimed for the new resin (known as Epophen M-777), are absence of inconvenient exotherm, even in large masses; greater strength and toughness of castings; and lower cost.

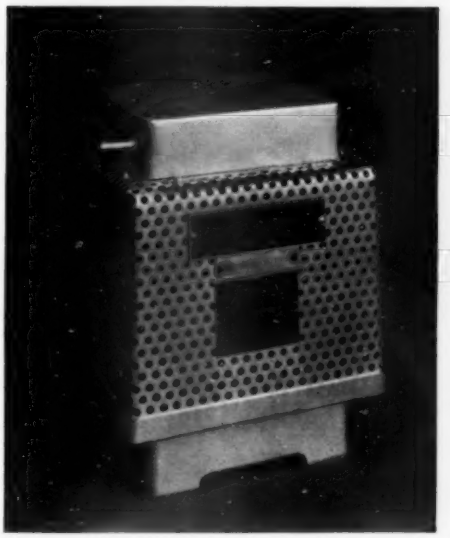
As a contact adhesive that will bond wood, metals, glass, plastics, leather—indeed practically any ordinary material—without pressure, Epophen comes very near to being the universal glue. There are so many potential uses of Epophen that Leicester, Lovell anticipate many enquiries for small quantities. To meet this expected demand and to facilitate initial small scale testing by industrial users, a compact test kit has been brought out which provides suitable quantities of resin, catalyst and filler, together with complete instructions and equipment for measuring and mixing the adhesive. This test kit and further information are obtainable direct from the manufacturers.

Leicester, Lovell & Co., Ltd., North Baddesley, Southampton.

Small Melting Unit

THE first of a batch of specially made electric furnaces recently successfully completed its tests at Elecfurn Works, Watford. It is a small unit designed for the rapid melting of small quantities of gold, and can also be used for other metals the melting points of which are not above that of gold. This model has been developed for the export market and in order to keep the equipment simple and the capital cost low, automatic temperature control has been dispensed with and the insulation so adjusted that a charge can be melted rapidly without serious danger of overheating the furnace.

The equipment follows orthodox procedure in its construction, having an angle framework retaining insulating brick. Four special grooved refractory plates form the chamber, and each contains heating elements of alloy wire running horizontally in nine grooves. Upper leadouts are taken down through special corner bricks to a terminal assembly below the furnace, and lower leadouts are taken direct through the insulation: all have suitable refractory cover tubes. The base of the chamber is fitted with a small removable brick pier to support a crucible, and an outer covering of perforated steel plate protects the insulation. A well-insulated hinged lid is fitted, having provision for the insertion of a thermocouple between the crucible and chamber refractories. Temperature regulation is effected by means of a hand-operated energy-regulator type controller. The maximum operating temperature



of the furnace is 1,200° C., and it has a nominal rating of 1·5 kW.

Wild-Barfield Electric Furnaces, Ltd., Watford By-Pass, Watford, Herts.

Shell Mould Maker

THE Polygram Simplex shell mould maker, a two-station hand-operated machine incorporating gas heating, was designed primarily to provide foundrymen who are interested in shell moulding, but who hesitate to spend a lot on equipment, with a simple compact mould maker with which they can experiment with a minimum of outlay. It is, however, capable of producing up to 60 shells per hour, and can, therefore, serve the smaller foundry as an efficient production unit. The machine is supplied with two cast iron ejector plates, two cast iron pattern plates, and one quart capacity

Polygram hand spray gun. In its design, emphasis has been placed on simplicity, rigidity and compactness, and it has a minimum of moving parts. As mould ejection takes place in the curing position, the overall length has been kept low and any sideways manipulation of the pattern plate by the operator is obviated. Automatic pattern plate clamping is used, and springless ejection of the shell is incorporated. Curing is effected by gas heaters situated below the pattern plate. Heat is thrown on to the shell to be cured by the polished internal reflecting surface of the oven-like covers.

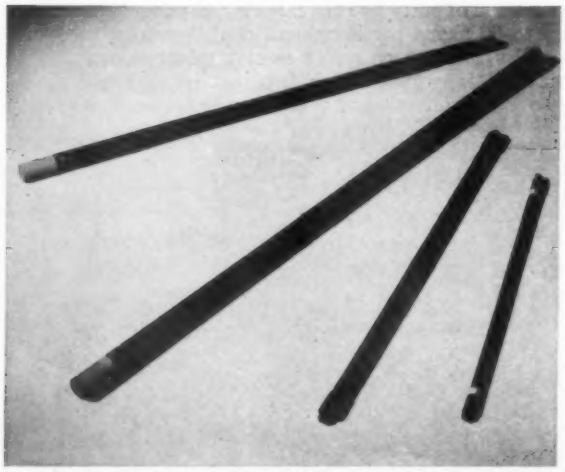
The standard machine has overall dimensions of 8 ft. 5 in. × 3 ft. 5 in. × 3 ft. 2 in. and takes a 14 × 12 in. plate, but a machine to take larger sizes can also be supplied.

Polygram Casting Co., Ltd., Power Road, Gunnersbury, London, W.4.

Silicon Carbide Heating Elements

THERE has been an appreciable increase in recent years in the use of silicon carbide heating elements for high temperature furnaces. They can be operated at high temperature and watt loadings, and can be brought up to temperature quickly without the need for any complicated control system. Moreover, they can be used in conjunction with all the normal types of refractories, and they do not require protection in special atmospheres. On the other hand they tend to "age," i.e., to increase in resistance with use. This characteristic necessitates the provision of sufficient voltage reserve to maintain the required power input, but, even so, frequent replacement of the elements is necessary as their resistance increases beyond the permissible maximum.

Hitherto, industry has been dependent on imported elements of this type, but many years of research and development work on the part of The Morgan Crucible Co., Ltd., have culminated in their producing an element marketed under the name of Crusilite. It is a one-piece silicon carbide tube, produced by a completely new technique, in which the central hot zone is in the form of a



spiral of the requisite length. It is suitable for working over a wide range of element temperature from 800° C. to 1,575° C. Perhaps its most important characteristic is the relatively slow rate of resistance increase in service. Being in one piece, it is also stronger than those elements made in three sections, with the hot zone in different material from the cold ends.

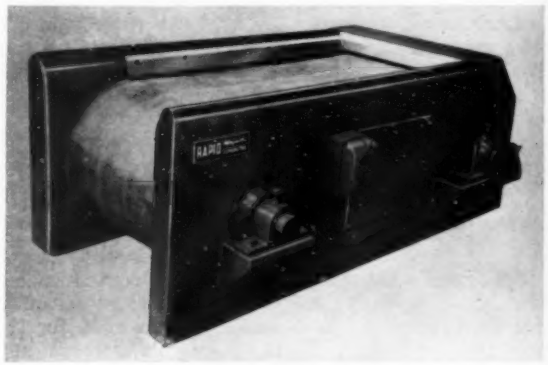
Such is the strength of the material used in its manufacture that a highly efficient terminal arrangement can be used, consisting of special metal terminal caps shrunk on to the metallised ends of the elements. Not only do these caps assure a good contact with the element, but they also provide an easy means of connecting to the power supply.

Suitable resistance values are stocked to cover the electrical conditions most frequently met in common practice. Despatches from stock will be within a tolerance of ± 10% of the nominal, but the resistance of all elements supplied as a set for any furnace will not vary by more than ± 5% from the mean, and, in many cases, by considerably less.

The Morgan Crucible Co. Ltd., Battersea Church Road, London, S.W.11.

Tramp Iron Diverter Unit

THE Rapid extra high intensity tramp iron diverter unit has been developed to cater for burdens too large, or iron too plentiful, to be dealt with by the conventional design of drum or pulley. The difficulties inherent in the



general design of the latter have been successfully overcome, and the new unit has a field strength approximately four times as great as the equivalent size of pulley or drum.

The high performance of this unit is due to unique features of design which concentrate and direct all generated magnetic flux to the operational sector only, ensuring a deep impinging field of high intensity coupled with high surface strength at the point where separation is to be effected. A patented feature is incorporated which ensures smooth unhindered discharge of extracted iron, obviating the normal difficulties encountered in achieving satisfactory release of tramp iron in powerful separators of this order. Total enclosure of the stationary energising coils, the absence of slip rings, incorporation of dustproof ball bearings throughout, coupled with a minimum of moving parts, ensure a long life with negligible maintenance. In application, the unit may be operated as a magnetic drum, replace the head pulley of existing or new conveyors, or be embodied in a self-contained separator.

Rapid Magnetic Machines, Ltd., Lombard Street, Birmingham, 12.

CURRENT LITERATURE

Book Notices

THE INSTRUMENT MANUAL

Second Edition. 628 pp., numerous illustrations. London, 1953. United Trade Press, Ltd. 84s. net.

WITHIN a comparatively short time of its publication in 1949, the first edition of this book was out of print, and as a result of numerous enquiries the publishers decided to issue a new and revised edition as soon as possible. In re-casting the contents, to make the *Manual* a fuller review of British instrumentation than was possible in the first edition, the sections on patents and general trends in instrument design have been omitted, and new sections introduced deal with aeronautical instruments, navigational instruments, meteorological instruments, surveying instruments, measurement and control of conductivity, telemetering, measurement of viscosity, and nucleonic instruments.

In addition, five sections have been completely re-written. They are those on optical instruments, measurement of fluid flow, measurement of hydrogen-ion concentration, general electronic instruments, and automatic control. The remaining sections have been extensively revised, although pressure of space has resulted in the omission in this edition of certain items, such as, for example, the automatic pilot. The buyers' guides at the end of each section have been made as complete as possible, whether the particular instruments have been described in the section or not.

The final chapters list the organisations interested in instrumentation and provide an alphabetical list of manufacturers. Reference is also made to publications associated with instrumentation.

ALUMINIUM IN BUILDING

Proceedings of a symposium on this subject held in June, 1953. 130 pp., numerous illustrations. London, 1954. The Aluminium Development Association, 33, Grosvenor Street, W.1. 4s.

THIS publication includes copies of the papers presented at the Symposium on Aluminium in Building, organised by the Aluminium Development Association and held at Claridge's Hotel, London, on June 30th, 1953, together with the preliminary remarks, discussion and authors' replies.

The first two papers provided a survey of aluminium in building from the separate points of view of the architect and the designer and craftsman; the third paper dealt with the specific applications of aluminium in roofing and cladding. The response to the discussion on the third paper also included replies to many points that had been raised throughout the day. These published "Proceedings" have particular value in that the discussion as printed takes into account contributors' further thoughts, and in that the replies also are reconsidered in the light of the full discussion.

The discussion was particularly encouraging in the lively interest expressed by architects and the building industry in the future possibilities for aluminium in their fields. This interest was repeated in the exhibition staged partly in the Association's headquarters and partly on an adjacent site which attracted many visitors over the four days in which it was open. Many technical enquiries subsequently received by the Association's consultant staff are the direct outcome of this symposium and exhibition.

BRITISH STANDARDS 1954 YEARBOOK

London, 1954. The British Standards Institution, 2, Park Street, W.1. 12s. 6d.

IF ready access to vital information be one of the canons of efficient business organization, the 1954 edition of this volume will prove as indispensable as its many predecessors to all engaged in industry, commerce and scientific research.

In it are listed no fewer than 2,500 British Standards current at March 31st, 1954, and a brief description is given of the subject matter of each. A comprehensive index simplifies reference. The usual information on the membership of the Institution's General Council, Divisional Councils and Industry Standards Committees is given, together with the names of representatives on the main Special Committees and Advisory Committees. Particulars of the work in hand of all the Industry Standards Committees are also given. British Standards under which the Institution's Certification Trade Marks are used are listed beneath the following headings: Electrical; Building; Plastics; Bedding and Furniture; Personal Safety; Miscellaneous.

Containing over 500 pages and attractively produced, the Yearbook is essential to all those whose work demands that they keep up-to-date with the increasing momentum of practical standardization and simplification.

MECHANICAL ENGINEERING RESEARCH, 1953

64 pp., 9 illustrations. London, 1954. Published by H. M. Stationery Office for the Department of Scientific and Industrial Research. 2s. 6d. (65 cents U.S.A), by post 2s. 8d.

THE Government's decision to resume, after a two-year interval, the programme of expansion planned for the Department of Scientific and Industrial Research after the war, will mean the completion of the major part of the building programme for the Mechanical Engineering Research Laboratory at East Kilbride. Details are given in this publication of the principal buildings to be constructed: they include laboratories for the study of heat transfer, mechanisms and metrology, plasticity, and high temperature creep and fatigue, and an administration building. It is expected that five of the seven divisions will be housed in their buildings by March, 1959, the two remaining divisions, Lubrication and Wear, and Mechanics of Solids, will remain in temporary accommodation, the former at Thorntonhall, and the latter at East Kilbride, but will have separate buildings provided for them later.

These points are discussed in that part of this publication which constitutes the Report of the Mechanical Engineering Research Board for 1953 to the Lords of the Committee of the Privy Council for Scientific and Industrial Research. The greater part of the book is, however, devoted to the Report of the Director, Dr.

D. G. Sopwith, and although the work discussed is mainly of an engineering nature, there is much of metallurgical interest to be found. For example, studies on the propagation of fatigue cracks and on the mechanics of formation and machine shaping of metals are obviously important to the metallurgist, as is the work on lubrication, wear and the mechanical engineering aspects of corrosion, whilst compression fatigue at spherical surfaces, and its relation to the pitting and eventual failure of gear teeth is of more than passing interest.

Trade Publications

In all forms of transport, reduction of deadweight without loss of structural strength leads to improved performance and more economical operation, and designers have long appreciated the advantages of construction in aluminium, combining as it does lightness in weight, adequate strength, and maintenance costs held to a minimum. With the development of the argon-arc welding process over the last few years, the difficulties formerly associated with the use of welding as a production means of jointing structures have been largely eliminated. T.I. Aluminium, Ltd., have recently issued a brochure, "Stiffened Panel Construction in Aluminium," in which the use of extruded sections in the form of integrally stiffened planks is described. The stiffened planks have the outer facing or skin welded together to form larger units or panels which form the basis of easy and economical construction of structures as diverse in purpose as the shallow-draft barges and road-rail containers described in the text.

"Some Notes on the Welding of Stainless Steel" is the title of a booklet recently issued by Rockweld, Ltd. The series of notes contained in it is designed to supplement available literature on the subject rather than to act as a complete manual on stainless steel welding. Frequently published information is so highly technical that the average fabricator has difficulty in understanding just how it applies to his particular job, whilst practical articles on the subject tend to ignore the reasons for recommended procedures. The aim of the booklet is to bridge the gap between theory and practice without going too deeply into either field.

The electrically heated box type furnaces manufactured by Royce Electric Furnaces, Ltd., are described in the Company's latest leaflet. They are manufactured in two standard ranges: the RBM with nickel-chromium heating elements for use up to a maximum temperature of 1,000° C.; and the RBH with Kanthal heating elements and a limit of 1,250° C. The RB type is a small, inexpensive furnace with the same temperature ranges. In addition to the standard equipment, illustrations are provided of plant designed and manufactured to customer's requirements.

We have received from Grey & Marten, Ltd., Southwark Bridge, London, S.E.1, a series of interesting technical publications. No. 1 deals with soft soldering, and in addition to discussing the best practice for cleaning and fitting parts for soldering, guidance is given on the selection and use of fluxes for soldering special alloys. Technical Publication No. 2 contains notes on the recommended practice for cleaning, surface treatment, tinning and soldering of aluminium coachwork, and the jointing of aluminium-sheathed cables. Methods of using Amalgan fusible alloys for tube bending, tool mounting and metal pattern manufacturing are featured in No. 3, whilst Nos. 4 and 5 are concerned, respectively, with white-metal bearing alloys, and silver soldering and brazing. Two leaflets also available list the British Standard brazing solders and soft solders, whilst a third deals with Amalgam Resinact self-fluxing solder.

The Industrial Products Division of Philips Electrical, Ltd., announce the introduction of a new monthly publication *Philips Serving Science and Industry*. This journal, which is similar in approach to the well known *Philips Technical Review*, will be devoted to new types of industrial equipment and industrial processes covering a wide field. Although emphasis will be laid on applied industrial electronics, articles dealing with new developments in arc and resistance welding and filtration will also be included from time to time. The first issue of the journal contains 32 well-illustrated pages dealing with the application of electronic instruments for measuring and recording vibration in power plants; the speeding up of woodwork production by means of dielectric-loss generators; a new installation for water purification at Rotterdam; different types of oscilloscopes and their application; and a survey of the construction and application of the electron microscope. The new publication is primarily directed to a technical audience, but many articles will be concerned with practical production problems of a widely differing nature which should prove of interest to industrial management.

We have received from High Duty Alloys, Ltd., a booklet with the title of "Extrusions in Hiduminium." An introductory section points out that any section obtainable in other metals can be extruded in Hiduminium, and that for the more unusual shapes its easy flow minimises wear on dies and tools. Attention is also drawn to the advantages of using extruded rather than built up sections, and the remainder of the booklet, which is devoted to illustrations of standard and special sections, gives some idea of the possibilities of the process.

Books Received

"Stainless Iron and Steel." By J. H. G. Monypenny, F.Inst.P., Vol. II. "Microstructure and Constitution." Third Edition Revised. Edited by Professor F. C. Thompson, D.Met., M.Sc. 330 pp., inc. numerous illustrations, name and subject indexes. London, 1954. Chapman & Hall, Ltd. 55s. net.

"Strength of Materials." By Arthur Morley, O.B.E., D.Sc., Hon. M.I.Mech.E. Eleventh Edition. 532 pp. inc. index, 231 diagrams and numerous examples. London, New York and Toronto, 1954. Longmans, Green & Co., Ltd. 21s. net.

"Copper: The Science and Technology of the Metal, Its Alloys and Compounds." Prepared under the editorial supervision of Allison Butts, with chapters by specialists. American Chemical Society Monograph Series. 936 pp. inc. name and subject indexes. New York and London, 1954. Reinhold Publishing Corporation and Chapman & Hall, Ltd. 160s. net.

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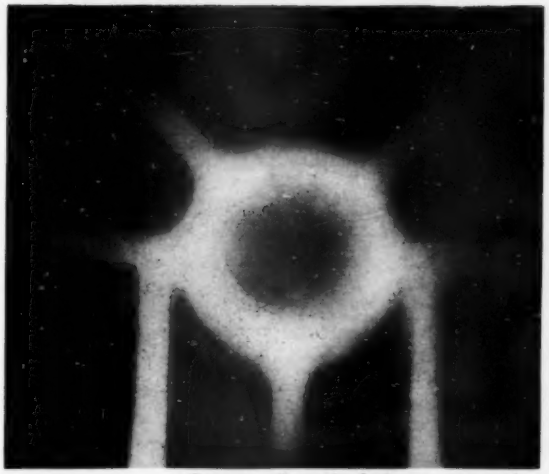

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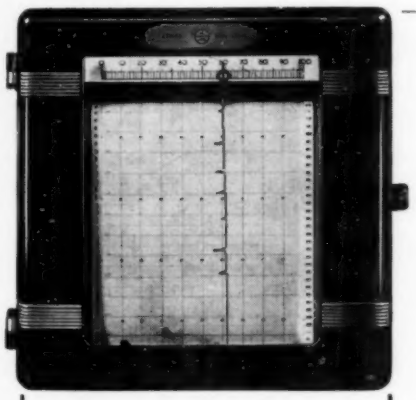

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The heating element is rated at 600 watts to give a reasonably quick rate of working, and a water cooling coil is built in to the cylinder wall. Moulds up to 2″ deep can be produced in approximately ten minutes. 10″×12″×18″ high. Weight 76 lbs.

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LABORATORY METHODS
MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS
SEPTEMBER, 1954 Vol. L, No. 299

The Absorptiometric Determination of Silicon in Ferrous Materials

A Report by the Glasgow Absorptiometric Panel

An absorptiometric method of determining silicon in all types of plain carbon and alloy steels and cast irons has been developed which meets the requirements of routine work since handling operations are reduced to a minimum. There is no loss in accuracy and the time required is considerably less than that based on reduction with stannous chloride.

FROM a critical observation of the various methods for the determination of silicon in ferrous materials, that of Gentry and Sherrington[1] appeared to offer the greatest field of application, especially in view of the variety of solvent acids which could be successfully employed. Preliminary tests of the method indicated that, while reasonably accurate determinations of the silicon content below 0·25% could be made, inherent errors became apparent when the method was adjusted to higher ranges of silicon, i.e., up to 4%.

In the present work, the conditions necessary to obtain accurate results over the range 0–4% silicon have been investigated, and a method devised which is suitable for different solvent acids, employing reagents at concentrations which have been shown to give maximum sensitivity and accuracy. The use of a prescribed volume of solvent acid and controlled evaporation during the process of solution ensures that all the silicon in solution is reactive, that none is rendered insoluble during solution of the sample, and that on dilution the solution will have a certain somewhat critical acidity. Excessive evaporation during digestion leads to low results. To avoid this, the solution volume (originally 50 ml. for a 0·25 g. sample) must not fall below the following figures :—

Silicon	Minimum Possible Volume	
	3·5% H_2SO_4	HCl/HNO_3
0·5%	15 ml.	24 ml.
2·0%	35 ml.	45 ml.

For samples containing 2–4% silicon, an extra 0·25 g. of high purity iron is added, and it is necessary to employ 100 ml. of the solvent acid.

Under certain conditions the HCl/HNO_3 solvent acid gives low results, and even forms the hydrogel of silicic acid, presumably by hydrolysis of silicon tetrachloride, and particularly in the presence of graphite. In such cases H_2SO_4/HNO_3 solvent acid gives satisfactory results, and the method finally adopted used three solvent acids in the following way :—

(I) 3·5% v/v H_2SO_4 for all unalloyed steels.
(II) HCl/HNO_3 solvent acid for alloyed steels.
(III) H_2SO_4/HNO_3 solvent acid for all cast irons.

Experimental Details

In the experimental work (which is recorded in the accompanying graphs) the silico-molybdate complex was reduced by ferrous sulphate in the presence of oxalic acid[1], the optical densities being plotted against the variable under examination. Graph I was obtained by dissolving steel samples of the same silicon content in varying amounts of the two solvent acids shown ; each at a fixed concentration. Such graphs are reproducible. Evidently by using different amounts of acid a series of calibration curves can be produced, and each such curve will provide a good method of analysis. Further, the analysis range can be varied by varying the amount of acid used initially, though it will be difficult to do this in normal practice. Alternatively, since both curves, within the limits of experimental error, have the same peak values and intersect close to these values, a method can be devised using the same amount of either acid (allowing a reasonable tolerance in measuring the volume used) which yields the same calibration curve. The depth of colour is not related in any simple manner to the normality of the solvent acids, namely, 1·22 N. for 3·5% v/v H_2SO_4, and 2·13 N. for HCl/HNO_3.

The Silico-Molybdate Complex

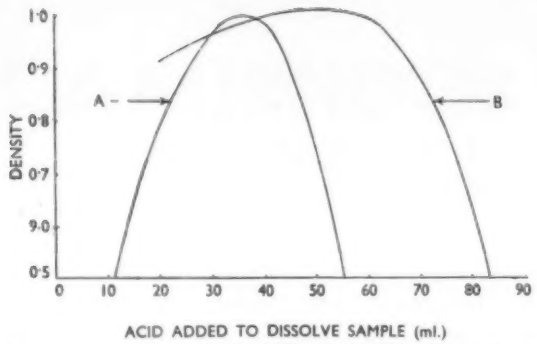
Graph I indicates the boundary condition of acidity within which the silico-molybdate complex forms. The optimum acidity for maximum complex formation can be recognised experimentally as the point where an incipient precipitation of ferric molybdate occurs ; with lower concentrations of acid the precipitate becomes heavier and the accuracy of the determination tends to fall.

Graph II shows the effect of adding fixed volumes of ammonium molybdate solutions of varying concentrations to a solution of silicon at a constant acidity. The shapes of the curves vary with the acid used, though they intersect near their maxima, which are quite sharp. If two or more solvent acids are to produce the same calibration curve it is evident that the amount of ammonium molybdate must be accurately controlled.

Reduction of the Silico-Molybdate Complex to Molybdenum Blue

Gentry and Sherrington[1] have shown that ferrous sulphate in presence of oxalic acid will satisfactorily

1 *J. Soc. Chem. Industry*, 1946, **65**, 90–92.



Graph I—Curve A: original HCl/HNO_3 solvent acid; curve B: 5% v/v H_2SO_4.

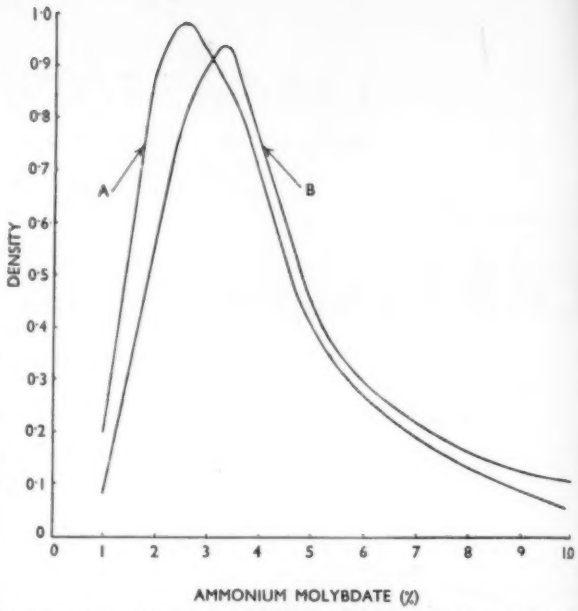
reduce the silico-molybdate complex preferentially in presence of similar complexes of phosphorus, vanadium, tungsten, etc., and of excess ammonium molybdate. Presumably, this depends on the lowering of the oxidation potential of the ferric-ferrous system by the oxalic acid. The maximum colour intensity is developed in 30 seconds and remains stable for at least 24 hours.

It has been found that the final colour varies with the amount of iron present, possibly because increase in the concentration of the ferric ion lessens the reducing power of the system. If, however, the correct amount of oxalic acid is present, it is possible to have a wide variation in iron content over which constant density readings can be obtained.

Graph III shows that the linear response obtained by using 5% w/v oxalic acid is much more favourable in the higher range of iron than that given by the 4% w/v solution recommended by Gentry and Sherrington[1]. The use of 5% solution allows the sensitivity of the method to be increased by doubling the sample weight, and at the same time the curve is suitable for the analysis of highly alloyed steels of much lower iron content.

Based on the information supplied by this preliminary work, three solvent acids of suitable concentrations have been chosen, such that the same volume of each can be used in the procedure.

Graph IV shows that, for the acid concentrations chosen and a sample weight of 0·25 g., the maximum colour reading is obtained using 50 ml. of any one of the three solvent acids, and that one calibration curve



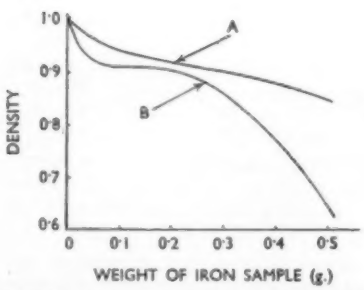
Graph II.—Curve A: original HCl/HNO_3 solvent acid; curve B: 5% v/v H_2SO_4.

should suffice for all the steel samples, using either 3·5 v/v H_2SO_4 or HCl/HNO_3 solvent acids, whilst a separate calibration is required for cast iron samples using H_2SO_4/HNO_3 solvent acid.

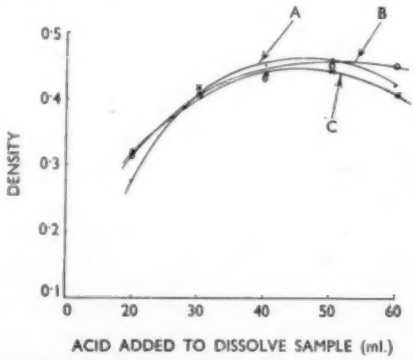
Graph V shows that, using 50 ml. of any of the three solvent acids, the optimum concentration of ammonium molybdate should be between 2·5% and 3·5% w/v. The results quoted in this investigation were all obtained using 2·5% w/v solution.

Although all the above concentrations are carefully controlled, a constant temperature must be maintained in the reduced solutions whilst optical density readings are being measured, otherwise accuracy will be sacrificed. It is recommended that the temperatures of the solutions should not be allowed to depart more than ±2° C. from that at which the calibration was made.

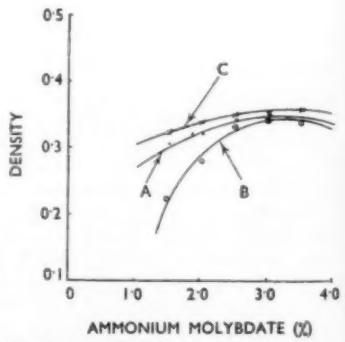
The method as finally adopted has been designed for all types of plain carbon and alloy steels, as well as plain and alloy cast irons. It meets the requirements of



Graph III.—Curve A: 5% w/v oxalic acid; curve B: 4% w/v oxalic acid.



Graph IV (using 5% w/v oxalic acid and 2·5% w/v ammonium molybdate)—Curve A: HCl/HNO_3 (solvent acid II); curve B: 3·5% v/v H_2SO_4 (solvent acid I); curve C: H_2SO_4/HNO_3 solvent acid III).



Graph V. (using 5% w/v oxalic acid)—Curve A: HCl/HNO_3 (solvent acid II); curve B: 3·5% v/v H_2SO_4 (solvent acid I); curve C: H_2SO_4/HNO_3 (solvent acid III).

routine work since handling operations are the minimum possible. All this has been achieved without loss in accuracy, and the time required is considerably less than that based on reduction with stannous chloride.

Method of Analysis

(1) *Dissolving Acid I*—Add 35 ml. sulphuric acid (sp. gr. 1·84) to 800 ml. water, cool and dilute to 1,000 ml. with water.

(2) *Dissolving Acid II*—To 500 ml. water add 125 ml. of hydrochloric acid (sp. gr. 1·18) or 140 ml. hydrochloric acid (sp. gr. 1·16) and 45·5 ml. nitric acid (sp. gr. 1·42). Cool and dilute to 1,000 ml. with water.

(3) *Dissolving Acid III*—To 500 ml. water add 36 ml. sulphuric acid (sp. gr. 1·84) and 45·5 ml. nitric acid (sp. gr. 1·42). Cool and dilute to 1,000 ml. with water.

(4) *Potassium Permanganate.*—0·225 g. potassium permanganate used per determination. (Solution or Analoids No. 4.)

(5) *Hydrogen Peroxide.*—20 vols.

(6) *Ammonium Molybdate Solution.*—2·5% solution in water (w/v).

(7) *Oxalic Acid.*—5% solution in water (w/v).

(8) *Ferrous Ammonium Sulphate.*—6 g. ferrous ammonium sulphate+1 ml. dissolving acid I dissolved in water and diluted to 100 ml.

Procedure

Dissolving acid I is used for all plain carbon and low alloy steels.

Dissolving acid II is used for all high alloy material. It can be used for plain carbon steel, but occasionally an insoluble residue is found which may necessitate an extra filtering operation as described below. This acid is not generally suitable for cast irons.

Dissolving acid III should be used for all plain and alloy irons; It is also suitable for many types of steel.

The calibration curves for acids I and II are coincident. The curves for acid III vary by a small amount from those for I and II; e.g., a 0·4% silicon steel dissolved in HCl/HNO_3 has an optical density of 0·655 using a 2 cm. cell, whereas the same steel dissolved in H_2SO_4/HNO_3 has an optical density of 0·685 using a 2 cm. cell. By judicious use of one or other of the acids listed, it is possible to decompose any material in about 10 minutes or less, especially if the sample is carefully prepared, free from coarse heavy drillings or millings.

Range 0–2·0% *Silicon.*

Weigh 0·25 g. sample into a 250 ml. Pyrex graduated flask, and dissolve with gentle heating in 50 ml. of a suitable acid. When the sample has decomposed, as indicated by the cessation of gas evolution, treat as follows:—

(*a*) If acids I and III have been used, add 0·225 g. potassium permanganate and boil for 2 minutes. Discharge the manganese dioxide precipitate by the dropwise addition of hydrogen peroxide. Cool, dilute to the mark, and shake thoroughly.

(*b*) If acid II has been used, boil off nitrous fumes for 2 minutes, cool, dilute to the mark and shake thoroughly.

Range 0–4·0% *Silicon.*

Weigh 0·25 g. sample and 0·25 g. sample of silicon-free iron into a 500 ml. Pyrex graduated flask. Dissolve in 100 ml. of a suitable acid and if acids I or III have been used, add 0·45 g. potassium permanganate, treat with hydrogen peroxide, cool, dilute to the mark, and shake thoroughly. If acid II has been used, omit the permanganate, boil, cool, dilute to the mark and shake thoroughly.

If the solutions obtained by the above procedures are found to be cloudy due to the presence of undecomposed carbides, filter off 50–60 ml. into clean dry beakers using a dry filter paper and discarding the first few ml. of the filtrate. Careful checks on the carbide residues obtained at this stage have shown that there is no loss of silicon, even in the carbides of the highly alloyed materials.

Transfer two 20 ml. aliquots into 50 ml. graduated flasks and treat as follows:—

(*a*) *Test Solution.*—Add 10 ml. ammonium molybdate solution and allow to stand for 10 minutes. Then add 10 ml. oxalic acid solution; mix and immediately add 5 ml. ferrous ammonium sulphate solution; dilute to the 50 ml. mark with water and mix thoroughly. The optical density may be read immediately if desired.

(*b*) *Compensating Solution.*—Add 10 ml. oxalic acid solution followed by 10 ml. of the ammonium molybdate solution and 5 ml. ferrous ammonium sulphate solution, mixing between each addition. Dilute to 50 ml. with water and mix thoroughly.

Measure the optical density of solutions (*a*) and (*b*) on the Spekker absorptiometer using a mercury vapour lamp, Ilford Spectrum filters No. 606 and the most suitable size of cell. The difference in optical density readings is due to the colour of the silicon in the sample, plus any small amount of silicon in the reagents. The silicon in the reagents is found by treating a silicon-free sample as described in the method and subtracting this value from the difference of (*a*) and (*b*). Convert the optical density due to the colour from the silicon in the sample to a percentage by reference to a calibration graph prepared from silicate solutions treated in the same environment and manner as described above.

The preparation of the standard silicate solution should be carried out as described in B.S. 1121 Part 15.

The routine technique described above should be followed if material of greatly varying composition is being analysed. If, however, batches of material of similar types of composition have to be analysed, the following procedure, which is much quicker and no less accurate, should be practised.

Weigh off along with the batch, a sample of silicon-free iron and treat as described above until the solution has been diluted to the 250 or 500 ml. mark as the case may be. Pipette off only one aliquot from this solution and one aliquot from each sample in the batch, and treat as described under "Test Solution." Set the Spekker absorptiometer w/w 1·2 or 1·0, as desired, and compare the high purity iron against water. In this way a useful check is obtained on the quality of the reagents and the general cleanliness of the instrument. Now reset the instrument, using the high purity iron solution in place of the water, and obtain density readings for all samples in the batch. Unless fairly high alloyed material is being analysed, the readings obtained are proportional to the silicon content in the samples. Since all alloying elements producing colours, e.g., chromium, nickel and cobalt, behave additively, their contribution to the optical density of the coloured solutions can be checked as follows:—

Treat an aliquot of the high purity iron and an aliquot from the batch as described under "Compensating

TABLE I.—TYPICAL RESULTS OBTAINED ON STEELS OF VARIOUS COMPOSITIONS BY DIFFERENT LABORATORIES.

Sample No.	Type of Steel	Silicon %								
		A	B	C	D	E	F	G	H	I
AP.12	8% Cr	3·20	3·26	3·22	3·15	3·20	3·20	3·18	3·14	3·25
AP.13	13% Cr	0·30	0·285	0·29	0·29	0·29	0·29	0·29	0·30	0·29
AP.14	18 : 8 Stainless	0·82	0·82	0·81	0·79	0·82	0·82	0·82	0·81	—
AP.15	BCS. 241 High Speed	0·25	0·23	0·23	0·23	0·23	0·23	0·235	0·23	0·225
AP.16	13% Ni, 13% Cr, 10% Co	0·75	0·73	0·72	0·73	0·72	0·72	0·725	0·72	0·72
AP.17	3% Si Iron	2·94	2·95	2·94	2·95	2·96	3·01	2·96	2·97	2·98
AP.18	BCS. 215 Plain Carbon	0·26	0·26	0·265	0·265	0·265	0·265	0·26	0·26	0·265

TABLE II.—TYPICAL RESULTS OBTAINED ON CAST IRONS OF VARYING COMPOSITIONS BY DIFFERENT LABORATORIES.

Sample No.	Type of Iron		Silicon %							
			A	B	C	D	E	F	G	Grav.
AP.19	1·42% Ni, 0·84% Mo	Millings	2·06	2·02	2·02	2·09	2·06	2·02	2·08	2·07
AP.20	1·42% Ni, 0·84% Mo	100 Mesh	2·08	2·00	2·00	2·09	2·08	2·02	2·10	2·07
AP.21	3·16% Ni, 1·13% Cr	Millings	2·46	2·47	2·40	2·43	2·50	2·47	2·50	2·45
AP.22	3·16% Ni, 1·13% Cr	100 Mesh	2·47	2·50	2·41	2·44	2·52	2·48	2·45	2·46
AP.23	15% Ni, 1·41% Cr, 7·37% Cu	Millings	0·61	0·60	0·63	0·62	0·62	0·615	0·60	0·62
AP.24	15% Ni, 1·41% Cr, 7·37% Cu	100 Mesh	0·60	0·61	0·62	0·62	0·62	0·625	0·61	0·62
AP.25	20% Ni, 2% Cr	Millings	3·78	—	3·72	3·83	3·77	3·70	3·70	3·74
AP.26	20% Ni, 2% Cr	80 Mesh	3·76	—	3·70	3·76	3·79	3·71	3·70	3·74

Solution." The contribution which the alloys make to the optical densities of the coloured test solutions should be subtracted from those of the coloured solutions before evaluating the percentage silicon in the samples from the calibration curves.

Notes

(1) All reagents should be of the highest purity obtainable. They should not be stored in glass containers for longer than 2 or 3 days. Ferrous ammonium sulphate solution should always be freshly prepared.

(2) Solutions should be prepared accurately and also be measured accurately with pipettes or burettes.

(3) Optical densities should be measured on the largest size of cell possible.

(4) Chromium is by far the worst of the interfering elements. Fortunately, this is not serious since a steel containing 16% chromium produces a colour due to chromium of only 0·04 density when using a 2 cm. cell. It is because of this that batch analysis on alloyed steels can be carried out using only one compensating solution as described above.

(5) The time saved by the method for batch samples over the more usual procedures is considerable, since only half the number of solutions have to be prepared and have their optical densities read on the Spekker absorptiometer.

(6) The technique of weighing into graduated Pyrex flasks causes no errors of any significance, since the hysteresis change of volume in heating a flask from 15°–100° C. and cooling is completely negligible.

(7) The temperature of the coloured solution should be maintained within a limit of 4° C., i.e., ±2° C.

Results

Silicon determinations have been made in a number of laboratories on a wide range of steels and cast irons using the method described above. Typical results are set out in Tables I and II.

APPENDIX

Constitution of Panel

The work described in this paper has been carried out by the Glasgow Absorptiometric Panel constituted as follows :—

Mr. E. K. Ballantyne (*Chairman*)	Colvilles Ltd., Clydebridge Works, Cambuslang.
Dr. A. B. Crawford	The Royal Technical College, Glasgow.
Mr. S. K. Christie*	Stewarts and Lloyds Ltd., Clyde Tube Works, Coatbridge.
Mr. G. Croall	Guest, Keen, Nettlefolds Group Research Laboratories, Wolverhampton.
Mr. A. R. Cruikshanks	Renfrew Foundries Ltd., Hillington.
Mr. K. Dixon†	Wm. Jessop and Sons Ltd., Sheffield.
Mr. H. Groom	Bragg Laboratories, N.O.I.D. Sheffield.
Mr. J. L Hutchison	Albion Motors Ltd., Glasgow.
Mr. J. Kyle	Wm. Beardmore and Co. Ltd., Glasgow.
Mr. J. Little	Colvilles Ltd., Dalzell Works, Motherwell.
Mr. J. Love	Lanarkshire Steel Co. Ltd., Motherwell.
Mr. V. Matheson	Clyde Alloy Steel Co. Ltd., Craigneuk.
Mr. W. Y. McMath	Rolls Royce Ltd., Hillington.
Dr. R. L. Mitchell	Macaulay Institute for Soil Research, Aberdeen.
Mr. R. Reid	Stewarts and Lloyds Ltd., Clydesdale Works, Mossend.
Mr. L. Russell	Babcock and Wilcox Ltd. Renfrew.
Mr. J. Sneddon	British Cast Iron Research Association, High Blantyre.

* Now with the Consolidated Pneumatic Tool Co. Ltd., Aberdeen.
† Now with the National Coal Board.

Electrical Equipment for Steelworks

The General Electric Co., Ltd., has been entrusted by Messrs. Richard Thomas & Baldwins, Ltd., with a contract valued at £238,000 for electrical plant and equipment for the Ebbw Vale Steelworks, where an existing 3-stand tandem cold mill is to be converted into a 4-stand mill. The order covers two 3,000 h.p. and one 750 h.p. twin-armature D.C. motors, a 6-machine motor-generator set driven by a 9,000 h.p., 11 kV. synchronous motor, and all the associated A.C. and D.C. switchgear, together with control gear embodying G.E.C. control exciters. The electrical plant and equipment for the original mill, which has been in service since 1938, was also supplied by The General Electric Co., Ltd.

Simultaneous Determination of Copper, Iron, Lead and Zinc in Copper-Base Alloys

By J. Kinnunen, M.Ph., and B. Wennerstrand
Outokumpu Oy Metalworks, Pori, Finland

A procedure is suggested, based in part on known methods, for the rapid analysis of brasses and bronzes. Apart from the overall saving of time, it is possible by its use to check the composition of melts of these alloys before the metal is cast.

THE production of brasses and bronzes calls for careful analytical control, and in brass mills an enormous number of copper, lead and zinc determinations are made annually for this purpose. In such circumstances, any successful attempt to shorten and simplify analytical procedures is of considerable importance. The method developed by the present authors for the analysis of copper, lead and zinc in concentrate[1] can also be used, with appropriate modifications, in the analysis of brasses and gun metals.

Reagents

EDTA Solution (0·05N)—18·605 g. disodium ethylenediaminetetra-acetate dihydrate dissolved in 1 litre of distilled water. The 0·01N solution is prepared by dilution.

Buffer Solution—350 ml. concentrated aqueous ammonia and 54 g. ammonium chloride dissolved in distilled water and made up to 1 litre.

Manganese Salt Solution of EDTA—0·05N solution of manganese sulphate titrated with 0·1 and 0·01N EDTA solution, using buffer solution and Eriochrome Black T as indicator, until the colour turns blue.

Sodium Thiosulphate Solution—40 g. sodium thiosulphate dissolved in 1 litre of distilled water.

Ericohrome Black T.—0·2 g. dye dissolved in 50 ml. alcohol.

DDCA Solution—2% solution of sodium diethyl dithiocarbamate trihydrate in distilled water.

Other Reagents—Solid tartaric acid; Rochelle salt; sulfamic acid; ammonium fluoride; ammonium bifluoride; boric acid; ascorbic acid; nitric acid (1 : 1); concentrated hydrochloric acid; 8% solution of potassium iodide; iodide-thiocyanate solution containing 5 g. potassium iodide and 60 g. ammonium thiocyanate (per litre of distilled water); concentrated aqueous ammonia; 20% solution of potassium cyanide; and 4% solution of formalin.

Procedure A

Copper.

Dissolve 0·5 g. sample in a 400 ml. beaker with 15 ml. nitric acid (1 : 1) and 3–4 g. tartaric acid. If the tin content is high, add also a few drops of hydrochloric acid. When the sample is dissolved, add about 0·05 g. sulfamic acid and boil to destroy brown fumes.[2] Cool the solution, add 25 ml. 8% potassium iodide solution or 10 ml. of iodide-thiocyanate solution and titrate with sodium thiosulphate solution, standardised against pure copper, 1 ml. of solution corresponding to 10 mg. of copper. At the end of the titration add some starch or, preferably, thiodene indicator, and titrate until a drop of thiosulphate solution causes no further colour change.

If iron is present in appreciable amounts and must be taken into account, omit the addition of tartaric acid, neutralise before titration the excess of acid with concentrated aqueous ammonia (about 6 ml.), and add solid ammonium bifluoride (0·2–2 g.) until the iron precipitate is dissolved: then titrate copper as described above.

Iron.[3]

After the titration of copper, add 1–2 g. boric acid and 10 ml. nitric acid (1 : 1) (free from oxides of nitrogen), and titrate iodine liberated by ferric iron with sodium thiosulphate solution. If iron is to be determined, iodide-thiocyanate solution cannot be used in the copper titration.

Lead (+ Manganese).[4-6]

Add 2 g. tartaric acid or mannitol, if not already added, into the solution after the copper or iron titration, followed by 0·1–0·3 g. ascorbic acid, 15 ml. 20% potassium cyanide solution and 20 ml. concentrated aqueous ammonia. Cool the solution, add 5–10 ml. manganese salt solution and titrate lead (+ manganese) with 0·01N EDTA solution, using Eriochrome Black T as indicator.

In the presence of aluminium add, before the titration of lead 2–3 g. ammonium fluoride into the ammoniacal solution, heat to boiling and cool.[7, 8] Alternatively, to mask aluminium add 1–2 g. sulfosalicylic acid after the titration of iron.[9]

Zinc.[10-12]

After the lead titration, add 20 ml. of 4% formalin solution and titrate zinc with 0·05N EDTA solution, using Eriochrome Black T as indicator. Repeat the addition of formalin solution (followed by further titration) until the solution no longer turns red (about 30 ml.).

Since large amounts of tartrate interfere, excess is to be avoided, and mannitol is preferred to tartaric acid as an addition before the titration of lead.

The foregoing procedure, partly based on known methods, permits the determination of copper, lead and zinc in leaded brass from the same initial weight. If preferred, the initial weighing can be omitted and the analysis carried out without the use of a balance.

This method permits rapid control of gun metals, copper, lead and zinc being determined in about 15 minutes, so that the analysis can be completed before casting. The tin content is obtained by difference, or it can be determined on a separate initial sample according to Kinnunen and Merikanto.[13] The result with this tin method seems to have been good as it has been republished, with slight modifications, by Rapport[14] and Goldberg.[15]

Procedure A fails if the lead and zinc contents of the alloy are low. In this case, the extraction with sodium diethyl dithiocarbamate[16] is to be preferred as outlined below.

Procedure B

Dissolve 1–5 g. sample in nitric and hydrochloric acids, and add 10 ml. 10% Rochelle salt solution prior to a dropwise addition of concentrated aqueous ammonia until the solution turns blue. Cool and add from a burette 20% potassium cyanide solution until the blue colour just disappears (not more than 5 drops excess). Transfer the solution into a separating funnel, add 20 ml. 2% DDCA solution and extract twice with 10 ml. chloroform. Drain the extract into a 400 ml. tall beaker, add 10 ml. nitric acid (1 : 1) and boil off the chloroform. Add to the residue 5 ml. 10% Rochelle salt and 10 ml. ammoniacal buffer in excess. Then add dropwise 20% potassium cyanide solution until the solution is colourless, followed by 4 ml. in excess. Dilute the solution to 100 ml., add 5–10 ml. manganese salt solution and titrate lead with 0·01N EDTA solution, using Eriochrome Black T as indicator. Then add 4% formalin solution and titrate zinc with 0·01N EDTA solution as described in procedure A.

Acknowledgment

The authors are indebted to Mr. Petri Bryk, President of Outokumpu Oy, for permission to publish this paper.

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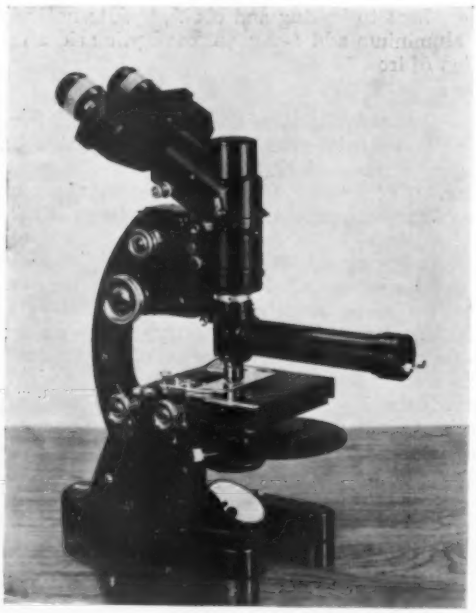
Exhibits of Metallurgical Interest at the Physical Society Exhibition

The exhibits at the Physical Society's annual exhibition of scientific instruments usually include a number of interest to workers in the metallurgical field. This year was no exception and in this issue we continue a short series of reviews in which such items will be described.

Variable Amplitude Phase-Contrast Microscope

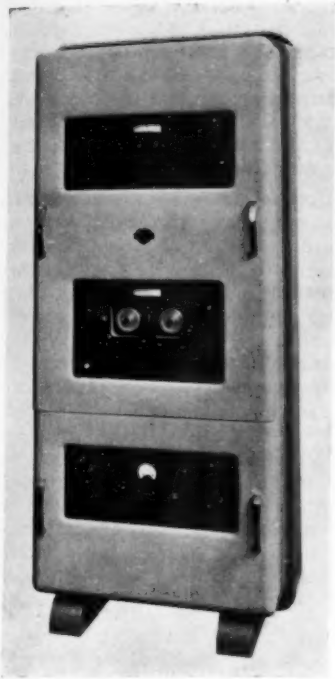
IN 1947, Cooke Troughton & Simms, Ltd., constructed a special phase-contrast microscope in which it was possible to vary both phase and amplitude continuously, to suit the characteristics of a particular specimen. This instrument was loaned to various institutions and used for the study of a great variety of objects, and, as a result certain conclusions were reached which have been used as a basis for the design of the instrument shown this year. As a result, a microscope has been produced which is simply adaptable to cover a wide range of phase-contrast and allied techniques.



C.T.S. variable amplitude phase-contrast microscope

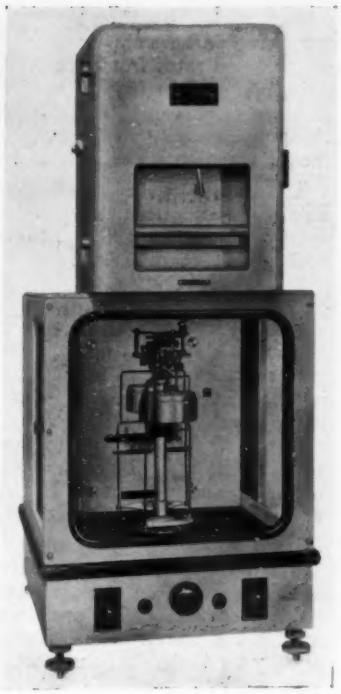
The object is illuminated by means of a phase-contrast condenser having the usual diaphragms mounted in its front focal plane. The image-forming light is deflected after passage through the objective on to a concave mirror, into the plane of which is projected the primary image. The concave mirror is tilted slightly so that the light is then directed on to a further plane mirror which reflects it along the axis of the microscope, at the same time forming an image of the back focal plane of the objective in an accessible position in the microscope tube. It is then possible to introduce polarising elements and quartz phase plates to enable amplitude variation to be obtained with equal efficiency at all powers. Subsequently, a projection lens is used to form an image in the eyepiece focal plane.

With this instrument it is possible to employ a range of normal apochromatic, fluorite and achromatic objectives, with or without the phase contrast method and, with any of them, to interchange phase plates at will. A Bertrand lens is included for examining the back focal plane of the objective. The instrument can easily be adapted for phase contrast microscopy with normal incident illumination. Variable amplitude methods, using polarised light and quartz phase plates, can be applied.



Above : Close-up of the tape head of the Mullard resistance furnace temperature programme unit.

Left : Mullard resistance furnace temperature control equipment. The top unit is the temperature controller, the middle unit is the programme equipment, and the bottom unit is the stabilised power supply.



Right : Stanton recording balance.

Xeroradiography

The demonstration of xeroradiography given by Ferranti, Ltd., showed one application of the xerographic principle, i.e., the production of photographs electrically on selenium plates for use with industrial and medical radiographic investigations. Positive or negative radiographs can be obtained in less than a minute from the actual exposure by this method. A considerable saving of time is therefore effected, and, moreover, the costs as compared with normal photographic techniques are considerably reduced as the plates can be used a very large number of times.

An electrostatic image of the radiograph is obtained on exposing a charged plate which consists of a very thin film of selenium deposited on a conductive backing plate. The image is made visible by applying a very thin film of charged powder to the surface of the plate, the powder adhering in accordance with the charge distribution on the plate itself. For re-use it is simply necessary to wipe the plate clean and re-charge.

Automatic Temperature Controller and Programme Unit

In the Mullard resistance furnace temperature controller, which is designed to control the temperature of a small resistance furnace (up to 5 kW. approximately), from a signal derived from a thermocouple unit, the required temperature is set by means of a potentiometer calibrated directly in millivolts, and the power of the furnace is regulated by means of thyratrons. Proportional and integral stabilisation controls are provided, and the range of control (depending upon the type of thermocouple used) can be up to 1,100° C. Accuracy of control can be obtained within ± 0·2° C., depending on the type of furnace with which the unit is used.

The furnace temperature programme unit intended to be used in conjunction with the controller, enables the temperature of the furnace to be permanent over long or short periods. The required temperature of the furnace is coded and punched on to a paper tape. The equipment facilitates this and compares it with a reference signal from the thermocouple in the furnace. The resulting error signal is fed into the temperature controller in the normal way. Temperatures may be coded in the range up to 1,000° C., in steps of 1° C.

Recording Balance

The recording balance shown by Stanton Instruments, Ltd., has been developed to give continuous records of weight change with time, when used in conjunction with customers' own auxiliary equipment. The balance is air-damped and suitable for a total load of 200 g. The object whose change of weight it is required to follow may be located on the rear pan or hung from it by means of a hook extending through the balance base. The sample may thus be located in a standard furnace, oven, refrigerator, humidity chamber, dry box or similar chamber, and the changes of weight are continuously indicated and recorded on a strip-type electronic recorder mounted above the balance.

The pen is driven by a servo motor and receives its information from a capacity follower plate located over the balance beam. The ability of the instrument to record change of weight is limited neither by the range of the chart nor by the range of a single beam deflection. Advantage is taken of the servo-driven mechanism to operate electric weight loading at the end of each full beam movement. By this means it is possible to follow the weight change up to ± 1 g. automatically.

The uses of the instrument include determinations of moisture, volatiles and ash; the determination of solvent evaporation rates from test panels; the preparation of oxidation or reduction curves from test pieces including sintered compacts, etc.; the behaviour of desiccants; the investigation of sublimation phenomena; and surface absorption and catalytical studies.

The instrument does not supersede the full thermobalance shown at a previous exhibition, in which the twin pen recorder produces curves for both temperature and weight changes.

Eddy Currents for the Study of Metal Surfaces

The use of electrical eddy currents in the study of metal surfaces is based on the fact that, when the currents are induced in a conducting material by an alternating magnetic field, they flow in and near the surface of the conductor. The strength of the currents and the depth to which they penetrate the conductor depend mainly on the rapidity of change in the magnetic field, and on the properties of the conductor, i.e., its resistivity and permeability.

When an alternating current is passed through a coil which is placed on or near a metal surface, a magnetic field is set up. This produces eddy currents in and around the metal. These currents in turn, through the agency of their own magnetic field, induce secondary currents in the coil. The original currents in the coil are thereby modified and the change can be measured by an electronic circuit. From this measurement, the properties of the metal surface can be assessed.

Four basic units are required to perform the necessary measurement; a source of alternating current of suitable frequency; a search coil designed to suit the type of surface to be studied; a detector senstitive to changes in the impedance of the coil; and an indicator unit providing a visual display from which the information required can be calculated.

A technique based on this principle is being used successfully by the British Iron and Steel Research Association to measure thin tin coatings (0–0·0005 in.) on steel sheet. In this case the effect is produced by the difference in the electrical properties between the coating and the base.

Another use to which this technique might be put is the measurement of the depth of the hardened layers in steel which has been surface-treated to resist abrasion. Preliminary tests have indicated that where there is no difference in the composition of the steel, as when surfaces have been hardened by flame or induction methods, the technique is likely to be difficult to apply. However, where the hardened surface is of a different composition from the core, as in carburised or nitrided surfaces, the method is likely to be more successful.

Manual Polarograph

The accuracy of recording polarographs is usually of the order of ± 1% for full-scale deflection; at intermediate points on the scale the error may be considerably greater and is apt to increase with the age of the instrument. In certain polarographic work, it is desirable to measure diffusion currents with an accuracy of ± 0·1%, for which purpose a potentiometric method of determining current and voltage may be used. Although determination of current—voltage curves by manual means is admittedly tedious, in routine analysis measurements are frequently made at a fixed polarising voltage, and the plotting of a complete polarogram is unnecessary. In applications in which precision, high current sensitivity and permanence of calibration are of primary importance, the potentiometric manual instrument offers advantages over an automatic recorder.

In the manual polarograph shown by Doran Instrument Co., Ltd., the current flows through a standard resistor and low-resistance potentiometer (the latter being connected in series-opposition to the potential difference across the resistor due to the current), and the unbalanced e.m.f. after amplification, is detected by a cathode ray tuning indicator. The polarising voltage and the corresponding peak polarographic current are indicated with an accuracy of ± 1% by the deflection of a voltmeter. The ranges are as follow: current, 0·00125 to 124μA; first indication 10$\mu\mu$A; voltage, 125 mV to 2·5 V, first indication 1 mV. By using the instrument in conjunction with a direct current potentiometer, the accuracy may be increased to ± 1%. A circuit for obtaining derivative polarograms is included, and the instrument, which is mains-operated, may also be used as an electrometer valve unit in *p*H measurements, or as a balance detector in bridge circuits.

Automatic Point Counter

The automatic point counter developed by James Swift & Son, Ltd., was designed for the model analysis of thin micro-sections of mineral aggregates by petrologists, but many suggestions have been made for its use in other fields. As the instrument can be fitted to a microscope equipped with an incident illuminator, it can be used for the analysis of opaque materials, such as thick mineralogical specimens and ores, or for the examination of alloys, and the estimation of inclusions in steel.

The instrument consists of a servo-operated traversing carriage which is attachable to the stage of any conventional microscope, and is coupled to an electrical recording or counting unit under the control of the observer. The traverse of the specimen carriage is not continuous, but is broken into a series of equally-spaced steps. These are triggered electrically in the "horizontal" direction by switches in the recorder unit, and spaced by a hand-operated knob in the "vertical" direction. Thus any preparation can be sampled by a symmetrical grid of points.

A series of push buttons is mounted in the recording unit, and these are labelled or coloured to conform to the identifiable constituents of the material under examination. The observer has only to identify the particle appearing under the cross wires of the microscope and then depress the appropriate push-button on the recording unit. The specimen then automatically moves on one space, to await a further identification of the next particle under the cross-wires. Upon completion of one horizontal traverse, the carriage is restored to its starting point and the next horizontal traverse selected by the vertical spacing knob. To offset the tedium of long sampling over a large homogeneous area of a preparation, and for certain counting purposes, an automatic contactor, driven from the power supply, can be connected to the standard instrument.